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Smoke Leakage Through Class A Boundaries

David T. Sheppard
Karl W. Aittaniemi

Underwriters Laboratories
333 Pfingsten Road
Northbrook, IL 60062-2096

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

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Groton, CT 06340-6096

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G.T. Gunther
Commanding Officer
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
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The Coast Guard technical contact is Mr. Louis Nash (860-441-2763) of the U.S. Coast Guard Research and Development Center. The Headquarters Project Officer is Mr. Klaus Wahle of the Office of Marine Safety, Security, and Environmental Protection.

16. Abstract

This report describes the testing and analysis of smoke leakage through fire doors, fire dampers, and fire stops while verifying their fire endurance meets International Maritime Organization (IMO) requirements for Class A. The report includes descriptions of the test procedures followed, the assemblies tested, and the results obtained.

The purpose of this project was to develop data that the United States Coast Guard could use when addressing a regulatory discontinuity in the fire test requirements for Class A divisions. Regulation 3.3 of Chapter II/2 of the 1974 International Convention for The Safety of Life At Sea (SOLAS) requires that Class A divisions be "constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour fire test". The standard fire test evaluates the passage of flame by use of a cotton wool pad. It has no provision for determining the passage of smoke. An objective of this project was also to develop a smoke leakage test protocol and to identify acceptance criteria to complement the standard IMO one hour fire tests for Class A divisions.

Tests were conducted on seven (7) fire doors, two (2) fire dampers, and two (2) fire stops. All samples tested were found to pass the one hour fire test without permitting the passage of flame past the door. Two A-15 rated fire doors were tested, and both marginally failed the thermal transmission requirement for the A-15 rating. All other samples were found to meet the acceptance criteria when applicable to the sample rating.

All samples permitted more leakage after the fire test than was allowed before the fire test. The report provides comparisons of leakage rates before and after the fire tests.

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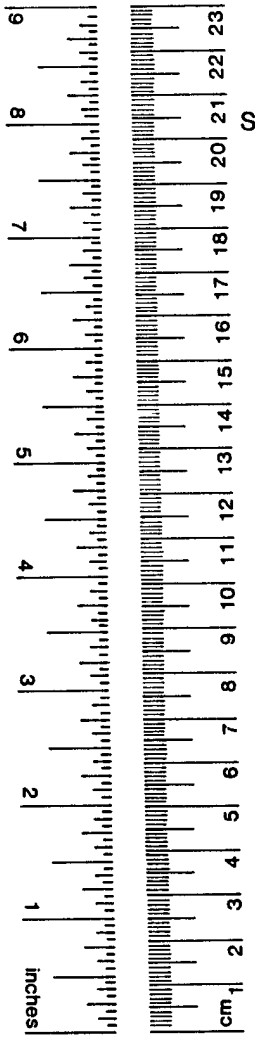
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

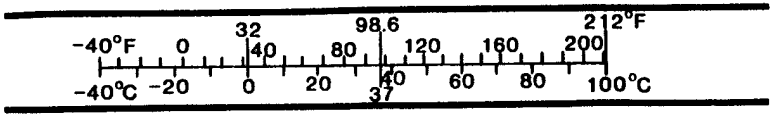
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (WEIGHT)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (EXACT)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (WEIGHT)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (EXACT)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Abbreviations

A-0	Class A bulkhead not rated for thermal transmission
A-15	Class A bulkhead thermally rated for 15 minutes
A-60	Class A bulkhead thermally rated for 60 minutes
ft	Feet
hr	Hours
IMO	International Maritime Organization
in.	Inches
kcmil	Electrical cable conductor diameter designation [1]
kg	Kilograms
lb	Pounds force
mm	Millimeters
m	Meters
min	Minutes
NA	Not Applicable
OR	Over range of the instrument
Pa	Pascals
sec	Seconds
SOLAS	International Convention For The Safety of Life At Sea
Type K	Chromel-Alumel Thermocouples
UL	Underwriters Laboratories Inc.
USCG	United States Coast Guard
'	Feet
"	Inches

1. INTRODUCTION

1.1 Background

The purpose of this project was to develop data that the United States Coast Guard (USCG) can use when addressing a regulatory discontinuity in the fire test requirements for Class A divisions. Regulation 3.3 of Chapter II/2 of the 1974 International Convention For The Safety of Life At Sea (SOLAS) requires that Class A divisions be "constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour fire test". The standard fire test [2] evaluates the passage of flame by use of a cotton wool pad. It has no provision for determining the passage of smoke.

An objective of this project is to develop a smoke leakage test protocol and to identify acceptance criteria to complement the standard International Maritime Organization (IMO) one-hour fire tests for Class A divisions.

This report describes the testing and analysis of smoke leakage through doors, fire dampers, and fire stops while verifying their fire endurance meets IMO requirements for Class A divisions. The report includes descriptions of the test procedures followed, the assemblies tested, and the results obtained. The results presented apply only to the materials actually involved in these tests.

When this effort started, the IMO SubCommittee on Fire Protection completed drafting a revised test standard for fire resistant divisions. This draft was contained in Annex 2 of FP 37/22/Add.1 [3]. On 4 November 1993, the IMO General Assembly adopted IMO Resolution A.754(18), Recommendation on Fire Resistance Tests For "A", "B", and "F" Class Divisions.

1.2 Method

The test program described in this report consisted of conducting tests on doors, fire dampers, and fire stops. Smoke leakage through the assemblies was evaluated before and after a fire test. The effect of the fire test on leakage rates was evaluated.

The smoke leakage tests were conducted in accordance with "Fire Tests-Evaluation of performance of smoke control door assemblies - Part 1: Ambient temperature test (ISO 5925/1 1981(E))"[4]. The fire endurance tests were conducted in accordance with "Revised Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions (Annex 2 of FP37/22/Add.1)"[5].

A movable test frame was constructed to contain five bulkhead assemblies. Each bulkhead assembly was designed to accept single swinging fire doors or fire dampers and fire stop systems. Each sample in the bulkhead was tested for air leakage, fire tested for a duration of one hour, allowed to cool, then tested for air leakage a second time.

1.3 Samples

Descriptions of the samples tested are provided in Table 1. A variety of items were used during the test to determine the variability in resisting passage of smoke. Tests were conducted on seven (7) fire doors, two (2) dampers, and two (2) fire stops. Each specimen tested was of a different design and whenever possible, samples within a class were procured from different manufacturers. A mixture of USCG and Underwriters Laboratories (UL) listed doors were used as the USCG doors were not tested in a furnace for approval. USCG doors are approved based on construction only. The test would provide information as to how well these doors would compare to the UL listed doors. Construction details of the samples are provided in Section 3.

In accordance with the fire test method, the samples were mounted in steel bulkheads for testing. When possible, multiple samples were mounted in each bulkhead. Table 1 provides a list of the bulkhead location of each sample.

Table 1. Sample Description

Sample No.	Sample Description	Bulkhead	Mounting Location on Bulkhead
1	Fire Damper (Class A)	A	Top north
2	Fire Damper (UL Listed 1 hour)	A	Top south
3	Fire Stop (Cable Transit)	A	Bottom north
4	Fire Stop (Pipe Penetration)	A	Bottom south
5	Fire Door (A-0 Rated)	E	South
6	Fire Door (A-0 Rated)	D	South
7	Fire Door (A-0 Rated)	D	North
8	Fire Door (A-15 Rated)	B	South
9	Fire Door (A-15 Rated)	C	South
10	Fire Door (UL Listed 1 hour)	B	North
11	Fire Door (UL Listed 1 hour)	C	North

The following discussion presents the apparatus, instrumentation, samples, procedures and results obtained.

2. APPARATUS

The test apparatus consisted of a large scale vertical furnace, an air leakage chamber, a moveable test frame, and steel bulkheads mounted in the test frame. The test samples were mounted in the steel bulkheads, which in turn were mounted in the movable test frame. The movable test frame was positioned on the furnace for fire tests and in front of the air leakage chamber for the leakage tests.

2.1 Air Leakage Chamber

The chamber was designed to be mounted on the masonry test frame completely covering the steel bulkhead in order to create an air-tight seal. The air leakage chamber consisted of an open-faced welded steel box with steel stiffeners. It contained a 203 mm (8 inch) diameter hole to accept an air duct for pressurizing the chamber. A removable entry hatch was located at the back of the chamber for accessing the samples when the chamber was mounted over a bulkhead. The chamber met the leakage criteria of 1 m^3/hr at 100 Pa when the chamber was completely sealed as

specified in paragraph 5.1 of Standard ISO 5925/1 1981. The chamber was also designed so static pressure probes could be mounted at the top and bottom elevation of the test samples.

The chamber was pressurized by a blower and damper system designed to blow air into the chamber so as not to directly impinge upon the test samples. The ductwork connecting the blower to the chamber incorporated a laminar flow element to measure the volumetric flow rate. A schematic of the air leakage chamber is provided in Appendix A, Figure A-1. A schematic of the ductwork is provided in Appendix A, Figure A-2.

2.2 Furnace

Underwriters Laboratories Inc.'s vertical furnace is capable of exposing a maximum test specimen of 4.25 m wide by 3.65 m tall (14'-0" x 12'-0"). The furnace is equipped with natural gasdiffusion burners symmetrically placed across the back wall. Windows are located on both sides of the furnace to allow observation of the surface exposed to the flame.

2.3 Test Frame

Figures A-3 and A-4 (Appendix A) show the elevation and construction details of the moveable test frame. The moveable test frame consisted of an outer steel frame and a 330 mm (13 inch) thick masonry wall constructed around the inside perimeter of the steel frame. Bulkhead mounting brackets were positioned along the inside perimeter of the opening. Bulkhead mounting brackets were constructed of 6.35 mm thick (0.25 inch) steel tees and MC12x31 channel.

2.4 Bulkheads

Figures A-5 through A-7 (Appendix A) show the construction details of the bulkhead assemblies. Bulkheads measured 3020 mm wide by 2480 mm high (118.9 by 97.6 inches) and were constructed from 4.5 mm (0.177 inch) thick plate steel as specified in Standard IMO FP 37/22/Add.1 Par. 2.1.1. A 64 mm (2.5 inch) thick ceramic fiber blanket insulation[1] was installed on the unexposed side of the bulkhead to provide an A-60 rating. The insulation had a 96.1 kg/m^3 (6 lb/ft^3) density. The insulation was anchored to the unexposed fire side face by impaling it on 102 mm long, 3 mm diameter (4 inch long by 0.12 diameter) steel pins and securing with locking

[1] Fiberfrax Part No. 764521000, 764561000 manufactured by Carborundum, Buffalo, New York.

caps. The pins were pre-welded to the bulkhead face in a staggered 457 mm (18 inch) on-center pattern.

2.5 Instrumentation

2.5.1 Data Acquisition

During the fire tests, temperatures, pressures, and linear displacement of the bulkheads were recorded. Temperatures and pressures were collected at a 2 1/2 minute scan rate using an Autodata 10 electronic data acquisition system. Linear displacement of the bulkheads was measured with a graduated ruler and recorded manually.

During the leakage tests, temperatures, flow rates, and pressures were recorded manually.

2.5.2 Fire Test - Furnace Temperatures

The furnace thermocouples were constructed and positioned in accordance with Standard IMO FP 37/22 Add. 1 Par 7.2 through 7.4. The thermocouples consisted of a bare bead supported by a ceramic insulator and steel tube. The bead extended 25 mm (1 inch) from the end of the insulator. Type K (Chromel-Alumel) thermocouples with a referenced accuracy of ±2.2°C (±4°F) were used. The furnace thermocouple locations are shown in Appendix A, Figure A-8.

2.5.3 Fire Test - Furnace Pressure

The static pressure probes were constructed in accordance with Standard IMO FP 37/22 Add. 1 Figure 5. The T-Probes were positioned at the top, center, and bottom of the bulkhead. The top location was 2480 mm (97.6 inches) from the bottom of the bulkhead and center location was 1240 mm (48.6 inches) from the bottom of the bulkhead. The pressure probes were connected to electronic pressure transducers with an accuracy of ±2%.

2.5.4 Fire Test - Sample Temperatures

Temperatures of unexposed surfaces were measured using 0.7 mm diameter (0.275 inch), Type K thermocouples, brazed to a copper disc 12 mm (0.47 inch) in diameter and 0.2 mm (0.008 inch) in thickness. The disc was covered with a 30 x 30 x 2 mm (1.18 x 1.18 x 0.08 inch) pad having a

density of 1000 kg/m³ (62.4 lb/ft^3). The pads were attached firmly to the surface with a ceramic adhesive. The thermocouples had referenced accuracy of ±2.2°C (±4°F).

Figures A-5 through A-7 (Appendix A) show the locations of the thermocouples on the steel bulkheads. Five thermocouples were attached to the unexposed side of each door sample with one in the center and the others in the center of each quarter panel.

2.5.5 Fire Test - Sample Deflection

The deflection of the door assemblies was measured using a graduated stick ruler from a reference line located at the horizontal centerline of the assembly.

2.5.6 Leakage Test - Volumetric Flow Rate

The air flow through the test assembly was determined from the pressure differential measured through laminar flow elements. Two flow elements were used depending on the quantity of air flow. The specifications of the laminar flow elements are provided in Table 2. The manufacturer's calibration curves used to convert pressure differential to volumetric flow rate are provided in Appendix B, Figures B-1 and B-2.

Table 2. Laminar Flow Element Specification

No.	Diameter (mm)	Model	Maximum Flow Range* m^3/hr (ft^3/min)
1	51	50MC2 2	175 (103)
2	152	50MC2 6	1850 (1100)

* measured at 21°C (70°F) and 3989 Pa (0.579 lb/ft²).

The pressure drop measured across the flow elements was measured using an inclined micromanometer capable of reading pressures with resolution of 0.25 Pa (0.001 inches water column).

2.5.7 Leakage Test - Static Pressure Measurements

The static pressure inside the test chamber was measured using an electronic manometer with a resolution of 1 Pa. Static pressure measurements on the North and South samples were made 100 mm (4 inches) above and 100 mm (4 inches) below the North and South samples respectively.

3. SAMPLES

Tests were conducted on eleven (11) test samples as described in Table 1. Tests were conducted on seven (7) fire doors, two (2) fire dampers, and two (2) fire stops. Each specimen tested was a different design. Whenever possible, samples within a class were procured from different manufacturers.

The following section provides a description of each test sample as well as the installation procedure used.

3.1 Sample Construction

3.1.1 Dampers

Two dampers were used in this test program. Both dampers measured 457 mm wide by 305 mm high (18 by 12 inches). A 74°C (165°F) UL Listed fusible link assembly was provided for each damper sample.

The Class A Rated Damper (sample 1) was a single blade design and is described in Appendix A, Figures A-9 through A-11.

The UL Classified damper (sample 2) was a two blade design and is described as follows: The frame consisted of identical top and bottom members formed of 2.7 mm (12 Ga.) galvanized steel with tabs folded and inserted into the channels of the 1.5 mm (16 Ga.) galvanized steel sides. The blades were formed from 1.5 mm (16 Ga.) galvanized steel. The minimum overlap of blade to blade along meeting edges was 6.4 mm (0.25 inch). A shaft assembly was provided on each end of each blade. It consisted of 11 mm (0.43 inch) hexagonal shaped steel galvanized axles pushed into blade crimp and blade clip. On one side, the axle was provided with a linkage crank arm.

The overall dimensions of the damper was 305 mm high by 457 mm wide (12 inches high by 18 inches wide). An schematic of the drawing is shown in Figure A-12. Thermocouple locations are shown in Figure A-13.

3.1.2 Fire Stops

The two fire stops tested consisted of a pipe penetration and a cable transit as shown in Appendix A, Figure A-14 and Figure A-15. The pipe penetration utilized two 25.4 mm (1 inch) diameter and one 12.7 mm (0.5 inch) diameter steel conduits. The cable transit utilized a bundle of five lengths of 500 kcmil power cable and a bundle of 54 lengths of 25 pair phone cables. A USCG Class A approved silicone foam sealing compound [2] was used for both fire stops. The total thickness of the finished sealing compound was 194 mm (7.6 inches).

3.1.3 Doors

The seven doors used in this test program were obtained from two manufacturers. Appendix A, Figures A-16 through A-19 show the general construction of the doors.

All test doors measured 914 mm in width by 2134 mm in height (35.9 by 84 inches) and all doors incorporated UL Listed hardware. The doors contained a single point cylindrical latch with a 19 mm latch throw. Each door utilized three mortise type steel hinges of the ball bearing type. The hinges were 114 mm high and 4 mm thick. The hinges were attached to the frame with steel screws.

Three A-0 rated doors were tested. Sample 5 was a plate steel door constructed from 3 mm (11 Ga.) plate steel. Samples 6 and 7 were constructed from 1.5 mm (16 Ga.) steel face sheets and 0.91 mm (20 Ga.) steel stiffeners with no insulation.

The two A-15 rated doors were constructed similar to the A-0 doors but contained 128.1 kg/m^3 (8 lb/ft^3) Coast Guard approved insulation adequate to insulate the doors for the A-15 rating.

[2] Dow Corning Corp 3 6548 Silicone RTV Foam Class A, B and C bulkheads and decks and may also be designated as 3M Fire Barrier 2001.

The two 1 Hour UL Classified fire doors were constructed of 1.2 mm (18 Ga.) steel face sheets and 0.76 mm (22 Ga.) steel stiffeners with 96.1 kg/m^3 (6 lb/ft^3) density mineral fiber insulation.

3.2 Sample Installation

3.2.1 Dampers

Each damper was continuously welded to the exposed fire side of a 900 mm (35.4 inch) long and 3.8 mm (0.15 inch) thick spigot. The spigot extended 450 mm (17.7 inch) on each side of the bulkhead. Each spigot was insulated up to the A-60 requirement. Each damper was installed in the open position.

3.2.2 Fire Stops

The cable and pipe penetrations were positioned in the spigot duct openings. The fire stop sealant was prepared and applied to the openings in accordance with the manufacturer's installation instructions. The fire stop sealant was then allowed to cure before testing.

3.2.3 Fire Doors

Each door sample was welded to the exposed side of the bulkhead with 102 mm (4 inch) long welds spaced 458 mm (18 inch) on-center around the door frame perimeter. The doors were received and installed pre-hung. The average clearances of the doors were confirmed as 2.4 mm (0.09 inch) along the latch and hinge jambs and top edge and 13 mm (0.5 inch) along the bottom.

4. TEST PROCEDURE

4.1 Pre-Fire Test Air Leakage

The following procedure was used to test the air leakage for each bulkhead.

1. The air leakage chamber was clamped and sealed to the MC12 x31 channels.
2. All samples were individually sealed with a clear plastic membrane and tape.

3. The chamber leakage was measured at the static pressures shown in Table 3. The leakage was measured by adjusting the air flow rate through the laminar flow element until the desired static pressure was measured in the leakage chamber. The pressure differential across the laminar flow element was then recorded.
4. The clear plastic membrane and tape was removed from one of the test samples.
5. The leakage was measured at the static pressure levels shown in Table 3. The leakage was measured by adjusting the variable speed blower attached to the laminar flow element until the desired static pressure was measured in the leakage chamber. The pressure differential across the laminar flow element was then recorded.
6. The sample was resealed with clear plastic membrane and tape.
7. Steps 4 through 6 were repeated for each test sample in the bulkhead.
8. After each individual sample was tested, the samples were again sealed off, and the chamber leakage was measured.
9. After the leakage tests, all tape and clear plastic membrane used to stop leakage through the samples were removed.

Table 3. Leakage Test Static Pressure Levels

No.	Pressure Pa. (lb/ft²)
1	5 (0.1)
2	10 (0.2)
3	20 (0.4)
4	30 (0.6)
5	50 (1.0)
6	70 (1.5)
7	100 (2.0)
8	5 (0.1)
9	100* (2.0)

* When the leakage rate at 100 Pa was too high for the instrumentation, the last leakage reading was taken at the highest possible static pressure.

4.2 Fire Test

During the fire test, the furnace was controlled in accordance with Standard ISO 834. The pressure inside the furnace was controlled in accordance with Standard IMO FP 37/22/Add.1.

The unexposed surface temperatures of the doors and bulkheads were recorded and averaged. The tests were conducted for a duration of one hour.

Visual observations were recorded for each test and the deflections of the assembly toward the furnace were measured from a reference line. The reference line was positioned along the horizontal centerline of the assembly, and the deflection readings were typically recorded at three locations. Maximum door separations from the door frame were recorded and a cotton pad test was conducted on the hot gases that were emitted through the separations. A gap gage was used during the tests to determine if a separation greater than 6 mm (0.24 inch) developed.

4.3 Post Fire Test Air Leakage

After exposure to the one-hour fire test, samples were allowed to cool for a minimum of 12 hours until they were cool to the touch. They were then subjected to the air leakage test as specified in Section 4.1 of this report.

5. TEST RESULTS AND DISCUSSION

The results for each fire test are summarized below. Each bulkhead is listed with specific items about the performance of the test samples as required by the Test Standard.

5.1 Fire Tests

Five furnace tests were conducted. The test sample locations in the bulkheads are described in Table 1. The schedule of tests is shown in Table 4.

Table 4. Test Schedule

Bulkhead	Test Date
A	5/12/94
B	5/17/94
C	5/24/94
E	6/7/94
D	6/22/94

Furnace temperatures and pressures are reported in Appendix C. Unexposed surface temperatures are provided in Appendix D. Observations and sample deflections are provided in Appendix E.

5.1.1 Furnace Performance

During the tests, the temperatures inside the furnace were controlled in accordance with Standard ISO 834. Figures C-1 through C-5 in Appendix C show the average furnace temperatures recorded during the fire tests compared to the ISO 834 temperature curve.

The pressure inside the furnace was controlled in accordance with Standard IMO FP 37/22/Add.1. Figures C-6 through C-10 (Appendix C) show the pressures recorded during the fire tests.

5.1.2 Bulkheads

Table 5 in Section 5.1.8 shows a summary of the bulkhead fire test results. The deflections measured in the bulkheads during the fire tests are tabulated in Appendix E. Plots of the temperatures measured on the unexposed side of the bulkheads are shown in Figures D-1 through D-5 located in Appendix D.

5.1.3 Fire Dampers (Samples 1 and 2)

The following is a summary of the results of the Fire Damper tests.

- No flaming occurred on the unexposed side of the fire stop penetration samples during the fire endurance test.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests conducted on the hot gases that were generated resulted in no ignition.
- No through openings developed in either sample.

5.1.4 Fire Stops (Samples 3 and 4)

The following is a summary of the results of the Fire Stop tests.

- No flaming occurred on the unexposed side of the fire stop penetration samples during the fire endurance test.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests conducted on the hot gases that were generated resulted in no ignition.

- At 13:35 min:sec, the temperature rise above ambient at a single point on the unexposed surface of the cable transit exceeded 180°C (356°F).
- The unexposed temperature rise of the pipe penetration surface did not exceed 180°C (356°F) at a single point during the 1 hour fire test.

5.1.5 A-0 Rated Fire Doors (Samples 5, 6, and 7)

The following is a summary of the results of the A-0 Fire Door tests.

- Steady flaming occurred from Sample 5 at 35:00 min:sec into the fire test. No flaming occurred on the unexposed side of samples 6 or 7.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad test conducted on Sample 5 at 23:00 min:sec resulted in no ignition. The cotton pad tests conducted on Samples 6 and 7 resulted in no ignition.

5.1.6 A-15 Rated Fire Doors (Samples 8 and 9)

The following is a summary of the results of the A-15 Fire Door tests.

- There were light intermittent licks of flame along the top edge of Sample 8 at 36:00 min:sec and at the top edge of Sample 9 at 15:00 min:sec.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests resulted in no ignition.
- The average unexposed temperature rise did not exceed 140°C (284°F) for either sample for the first 15 minutes of the test.
- One thermocouple on Sample 8 exceeded the 180°C (356°F) limit for a single point at 14:50 min:sec.
- One thermocouple on Sample 9 exceeded the 180°C (356°F) limit for a single point at 14:55 min:sec.

5.1.7 UL Listed 1-Hour Fire Doors (Samples 10 and 11)

The following is a summary of the results of the UL Listed Fire Door tests.

- No flaming occurred on the unexposed side during the fire test.
- It was not possible to insert a 6 mm (0.24 inch) gap gauge into any openings in the specimens.
- The cotton pad tests resulted in no ignition.

- The average unexposed temperature rise of Sample 10 and Sample 11 exceeded 140°C (284°F) at 14:58 and 12:02 min:sec, respectively.
- Samples 10 and 11 exceeded the 180°C (356°F) single point limit after 11:56 min:sec and 9:30 min:sec, respectively.

5.1.8 Summary

Tables 5 and 6 show a summary of the fire test results.

Table 5. Summary of Bulkhead Results

Bulkhead	Time for Average Temperature to Rise 140°C (284°F) Above Ambient (min:sec)	Time for a Single Temperature to Rise 180°C (356°F) Above Ambient (min:sec)	Maximum Unexposed Temperature °C (°F)	Maximum Deflection mm (inch)
A	Did Not Exceed	Did Not Exceed	208 (406)	64 (2.5)
B	55:00	Did Not Exceed	209 (408)	38 (1.5)
C	50:00	Did Not Exceed	215 (419)	63 (2.5)
D	52:30	Did Not Exceed	198 (388)	63 (2.5)
E	7:30	20:00	710 (1310)	80 (3.1)

Table 6. Summary of Sample Results

No	Sample	Time for Average Temperature to Rise 140°C (284°F) Above Ambient (min:sec)	Time for a Single Temperature to Rise 180°C (356°F) Above Ambient (min:sec)	Maximum Unexposed Temperature °C (°F)	Maximum Deflection mm (inch)
1	Fire Damper (Class A)	36:21	34:10	296 (565)	NA*
2	Fire Damper (UL Listed 1 hour)	56:15	58:40	183 (361)	NA
3	Fire Stop (Cable Transit)	22:36	13:35	451 (845)	NA
4	Fire Stop (Pipe Penetration)	27:31	13:55	453 (847)	NA
5	Fire Door (A-0 Rated)	4:19	4:47	749 (1380)	57 (2.2)
6	Fire Door (A-0 Rated)	10:42	10:59	569 (1056)	45 (1.8)
7	Fire Door (A-0 Rated)	12:24	12:25	534 (993)	38 (1.5)
8	Fire Door (A-15 Rated)	17:09	14:50	498 (928)	38 (1.5)
9	Fire Door (A-15 Rated)	15:10	14:55	467 (873)	38 (1.5)
10	Fire Door (UL Listed 1 hour)	14:58	11:56	547 (1016)	32 (1.25)
11	Fire Door (UL Listed 1 hour)	12:02	9:30	606 (1123)	32 (1.25)

5.2 Leakage Tests

Figures 1-5 show plots of the leakage rates measured for each sample as a function of static pressure in the leakage chamber. The leakage rates were corrected for chamber leakage by subtracting the average chamber leakage measured before and after each leakage test series. The readings were also corrected for atmospheric conditions using Equation 1 as outlined in the Standard. The uncorrected and corrected leakage rates are in Appendix F.

$$Q_a^* = Q_a\left(\frac{P_a+{}^{\Delta}P}{101325}\right)\left(\frac{293.15}{T_a+273.15}\right)\left[1-0.3795\left(\frac{M_w}{100}\right)\left(\frac{E_s}{P_a+{}^{\Delta}P}\right)\right] \quad \text{Equation 1}$$

Where:

Q_a^*	is the adjusted flow rate.
Q_a	is the measured flow rate.
P_a	is the barometric pressure, in Pascals.
${}^{\Delta}P$	is the pressure increase, in Pascals.
T_a	is the air temperature, in Celsius.
M_w	is the relative humidity, as a percentage.
E_s	is the saturated water vapor pressure, in Pascals.

Three of the door samples (samples 5, 7, and 11) became unlatched during the cool down period after the fire tests. These doors were pushed closed by hand to a friction fit and locked in place with a wooden wedge at the sill before the leakage tests were conducted.

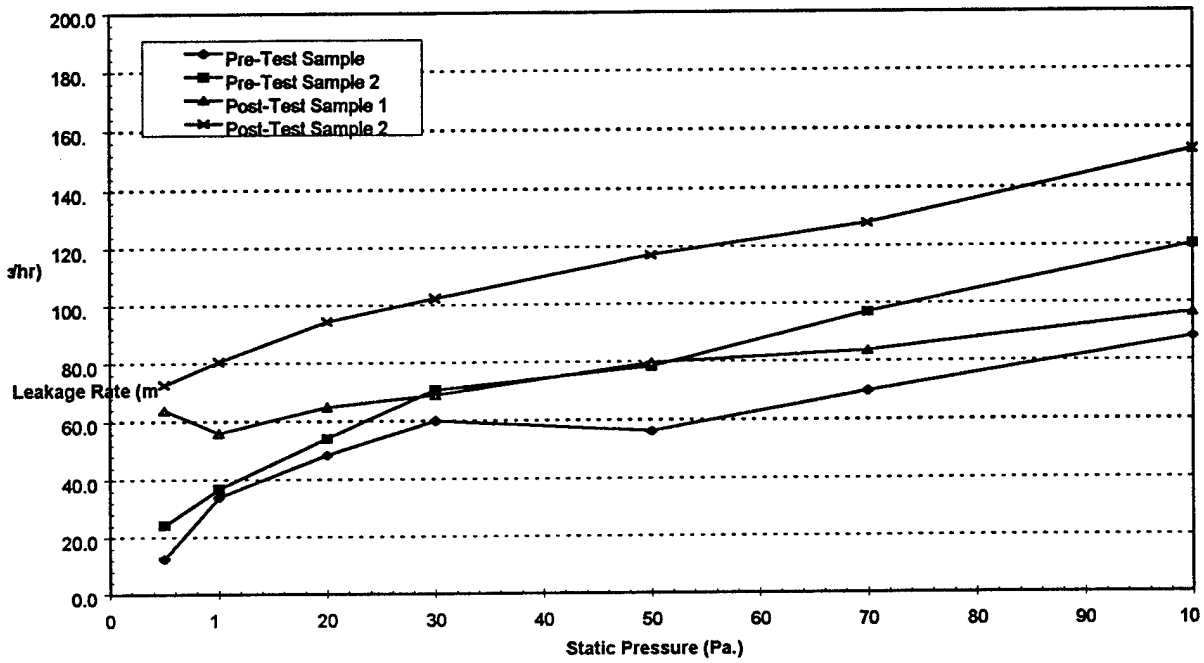


Figure 1. Fire Damper Leakage Rates

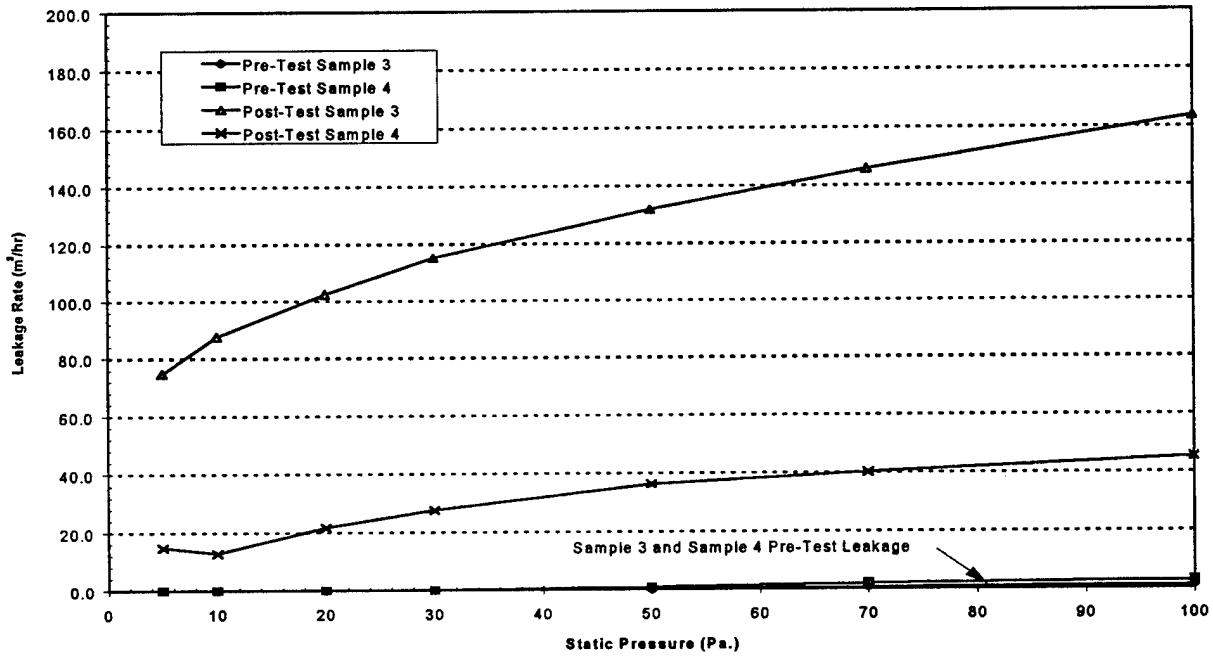


Figure 2. Fire Stop Leakage Rates

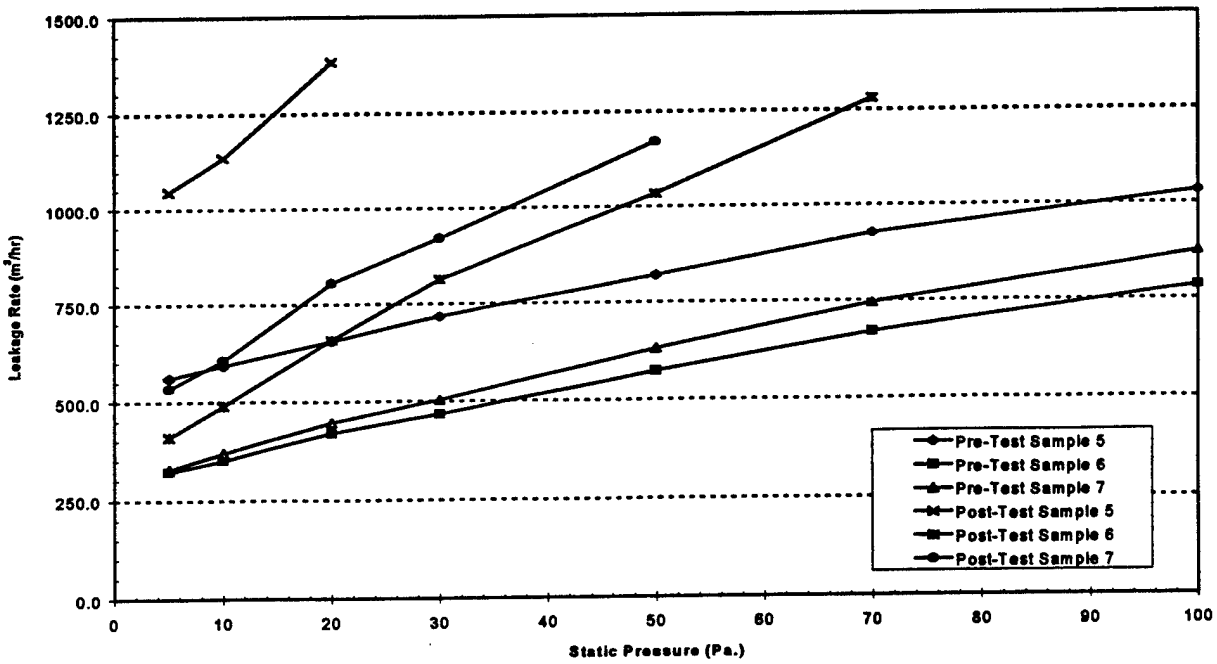


Figure 3. A-0 Fire Door Leakage Rates

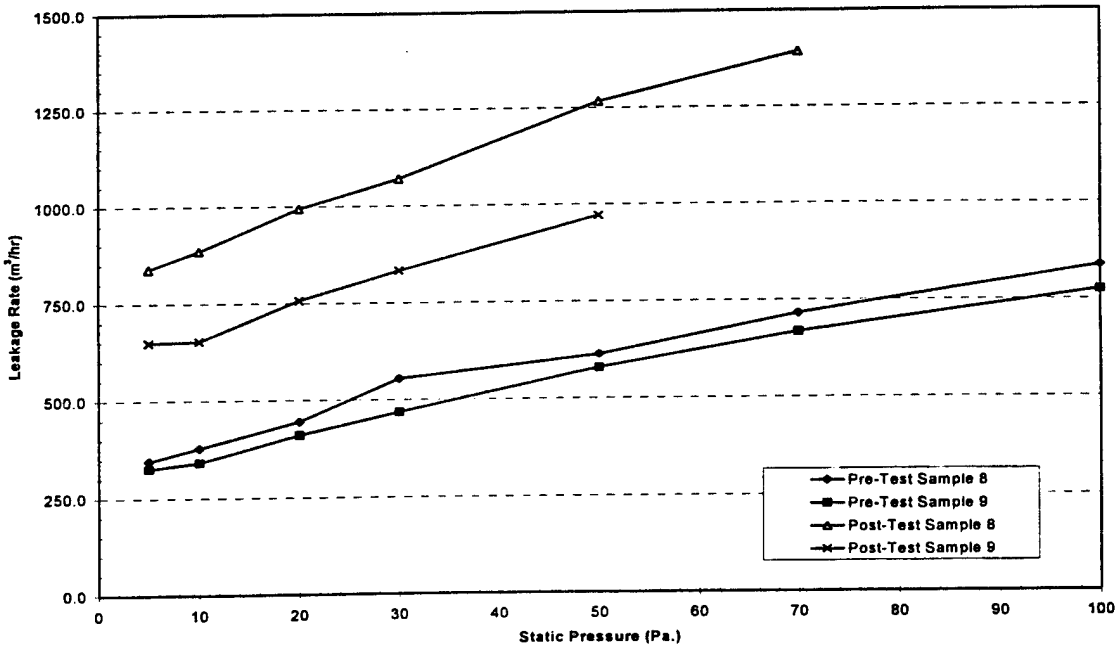


Figure 4. A-15 Fire Doors Leakage Rates

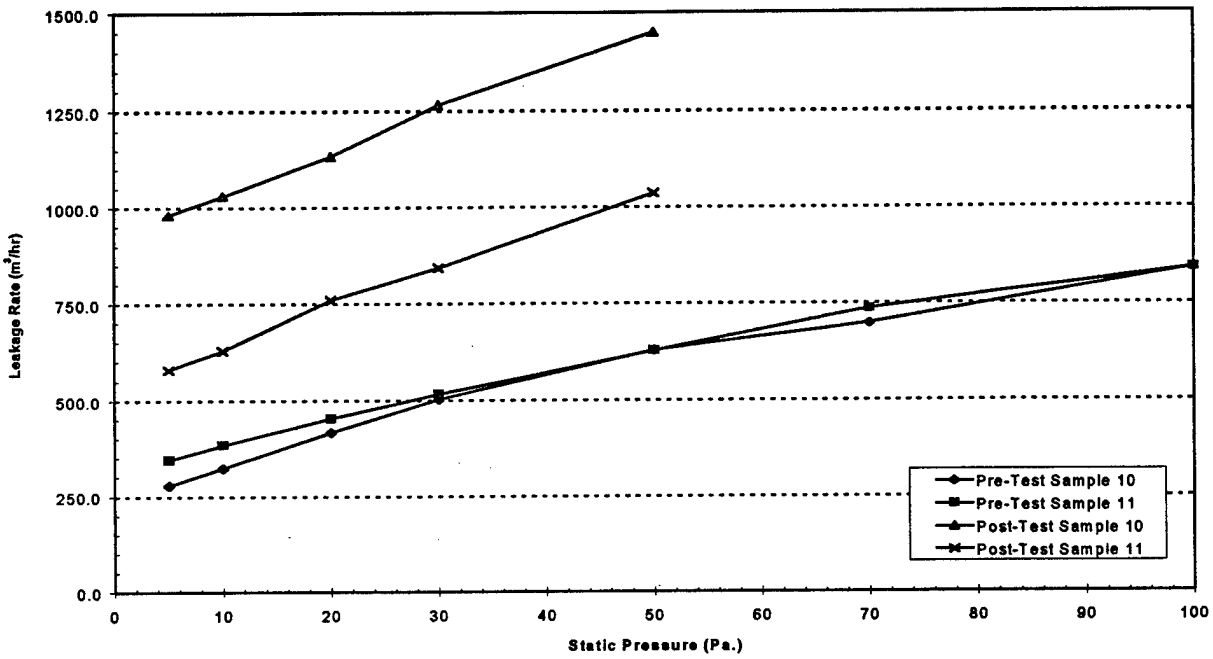


Figure 5. UL Listed 1-Hour Fire Door Leakage Rates

6. TEST METHOD CRITIQUE

6.1 Fire Test

The fire test standard does not indicate when to stop applying the test for flame penetration. From our understanding and from our discussions with overseas testing agencies, the cotton pad test is not required after the unexposed surface temperature of the specimen exceeds its intended insulation value (i.e., A-15 door exceeds 140°C rise average at 15 minutes). It is the Coast Guard's opinion that the cotton-wool pad test is to verify the integrity of the test specimen. This would identify whether a crack or opening could lead to the passage of hot gases sufficient to cause ignition of combustible material. The acceptance criteria for tests should be to periodically conduct the cotton-wool test for the duration of the test, 60 minutes for class "A" division fixtures.

The fire test method specifies that 30 x 30 mm asbestos pads be placed over the unexposed thermocouples. Asbestos pads can not be used in the United States for health reasons. The standard should be modified to allow a substitute pad material.

6.2 Leakage Test

One problem which is not addressed in the leakage test method is the cooling time required after the fire test. We allowed the samples to cool for a minimum of twelve hours after the fire test and did not conduct the leakage test until the assembly was cool to the touch.

Leakage protocol should address the following issues caused by the shifting of the assembly during the cool down period after the fire test.

- What should be the allowable system leakage be after the fire test?
- How can the test samples be prepared for the leakage test? Three of the fire doors in this test series sprung open during the cool down period. The doors were pushed closed to a friction fit, because the locking assemblies were inoperative.

The leakage protocol should address multiple samples in one bulkhead. Testing multiple samples in the same bulkhead reduces testing costs and provides faster turn-around time. When multiple samples are tested in one bulkhead, several procedural questions should be addressed.

- How should each sample be isolated for the leakage test?
- The frequency of chamber leakage measurements should be defined. Should the chamber leakage be measured after each individual sample is tested, or should chamber leakage be measured at the beginning and end of a series of leakage tests on one bulkhead? We feel that the system leakage should be measured before and after each specimen is tested because there was an appreciable difference in the system leakage.
- Where should static pressure measurements be made on bulkheads with multiple samples?

A recommended design for the leakage chamber should be provided. We used a reinforced steel chamber which totally covered the bulkhead and was mounted on the surrounding masonry wall. The advantage of this design is that the tightness of the seal was not affected by bulkhead

deflection.

In order to design the leakage equipment, a maximum leakage rate should be defined. We used a series of laminar flow elements with different ranges to measure the leakage rates of the test samples. On some leakage tests performed after the fire tests, we exceeded the maximum range of our largest flow element when testing at the higher static pressure ranges.

REFERENCES

1 UL 1581 - Reference Standard for Electrical Wires, Cables, and Flexible Cords, 2nd Ed., Underwriters Laboratories, Northbrook, IL, 1991.

2 IMO Resolution A.517(13), Recommendation on Fire Test Procedures of "A", "B", and "F" Class Divisions, International Maritime Organization, London, UK.

3 DTCG39-93-F-E00676 (DO 0008) Statement of Work, Section 3.3, June 18, 1993.

4 Fire Tests-Evaluation of Performance of Smoke Control Door Assemblies - Part 1: Ambient Temperature Test (ISO 5925/1 1981 (E)).

5 Revised Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions (Annex 2 of FP37/22/Add.1).

6 Van Wylen and Sontag, Fundamentals of Classical Thermodynamics, 2nd Ed. John Wiley and Sons Inc., New York, 1973.

1 UL 1581 - Reference Standard for Electrical Wires, Cables, and Flexible Cords, 2nd Ed., Underwriters Laboratories, Northbrook, IL, 1991.

2 IMO Resolution A.517(13), Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions., International Maritime Organization, London, UK.

3 DTCG39-93-F-E00676 (DO 0008) Statement of Work, Section 3.3 June 18. 1993.

4 UL 1581 - Reference Standard for Electrical Wires, Cables, and Flexible Cords, 2nd Ed., Underwriters Laboratories, Northbrook, IL, 1991.

4 Fire Tests-Evaluation of performance of smoke control door assemblies - Part 1: Ambient temperature test (ISO 5925/1 1981(E))

5 Revised Recommendation on Fire Test Procedures for "A", "B", and "F" Class Divisions (Annex 2 of FP37/22/Add.1)".

APPENDIX A
Construction Details

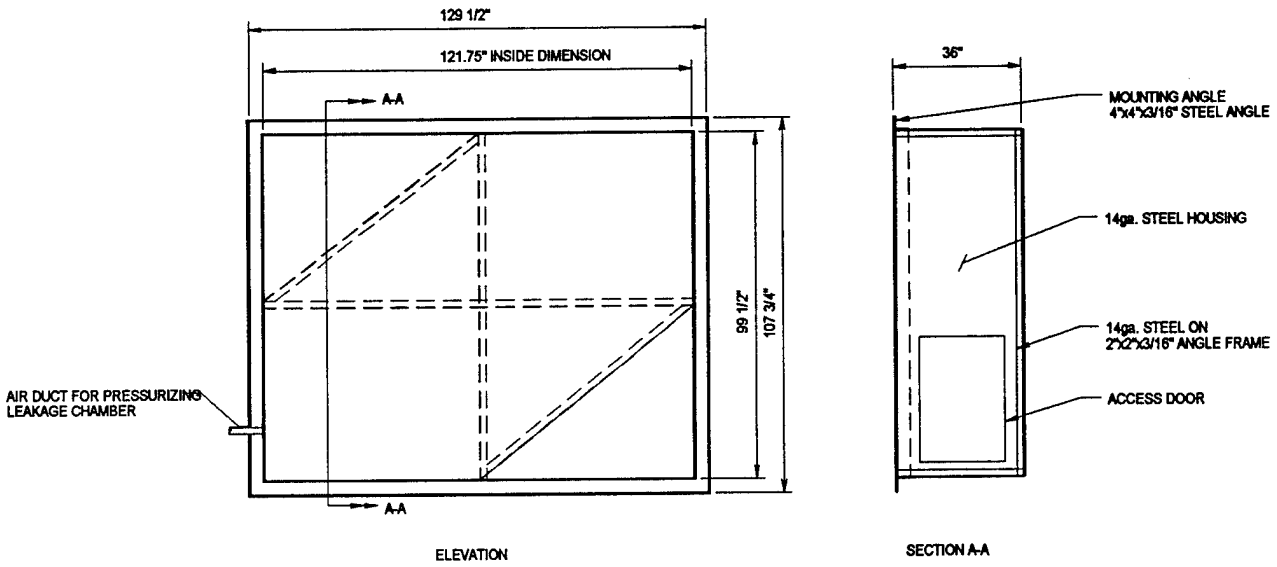


Figure A-1. Air Leakage Chamber

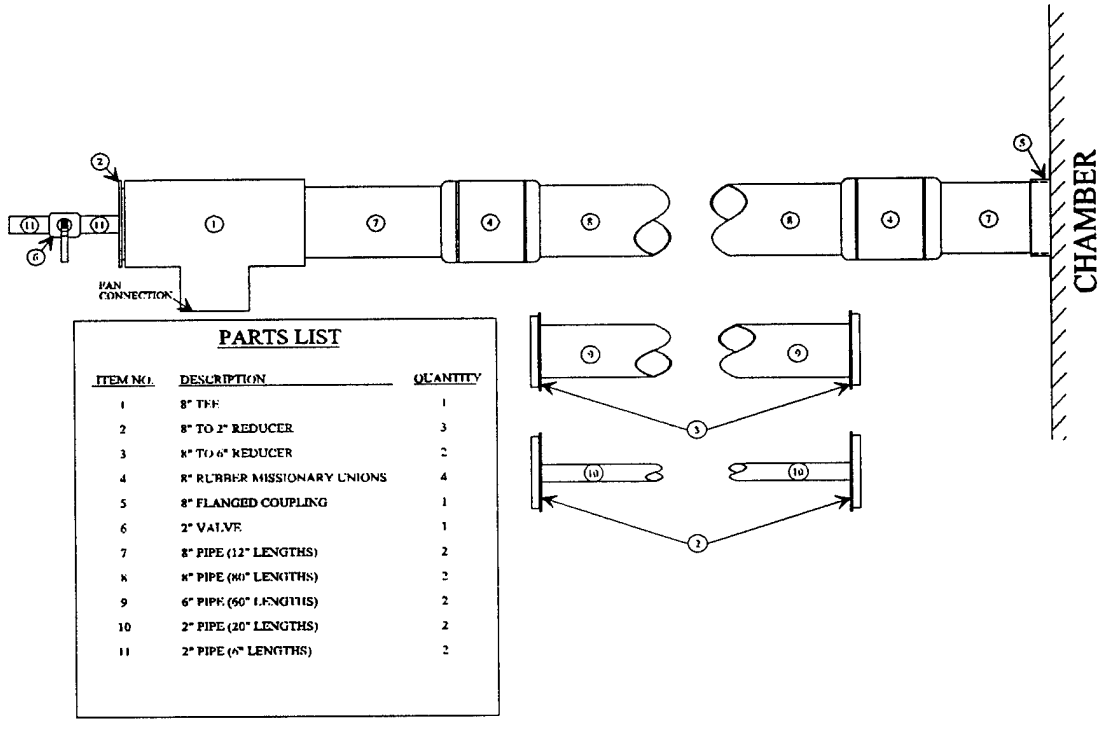


Figure A-2. Air Leakage Chamber Ductwork

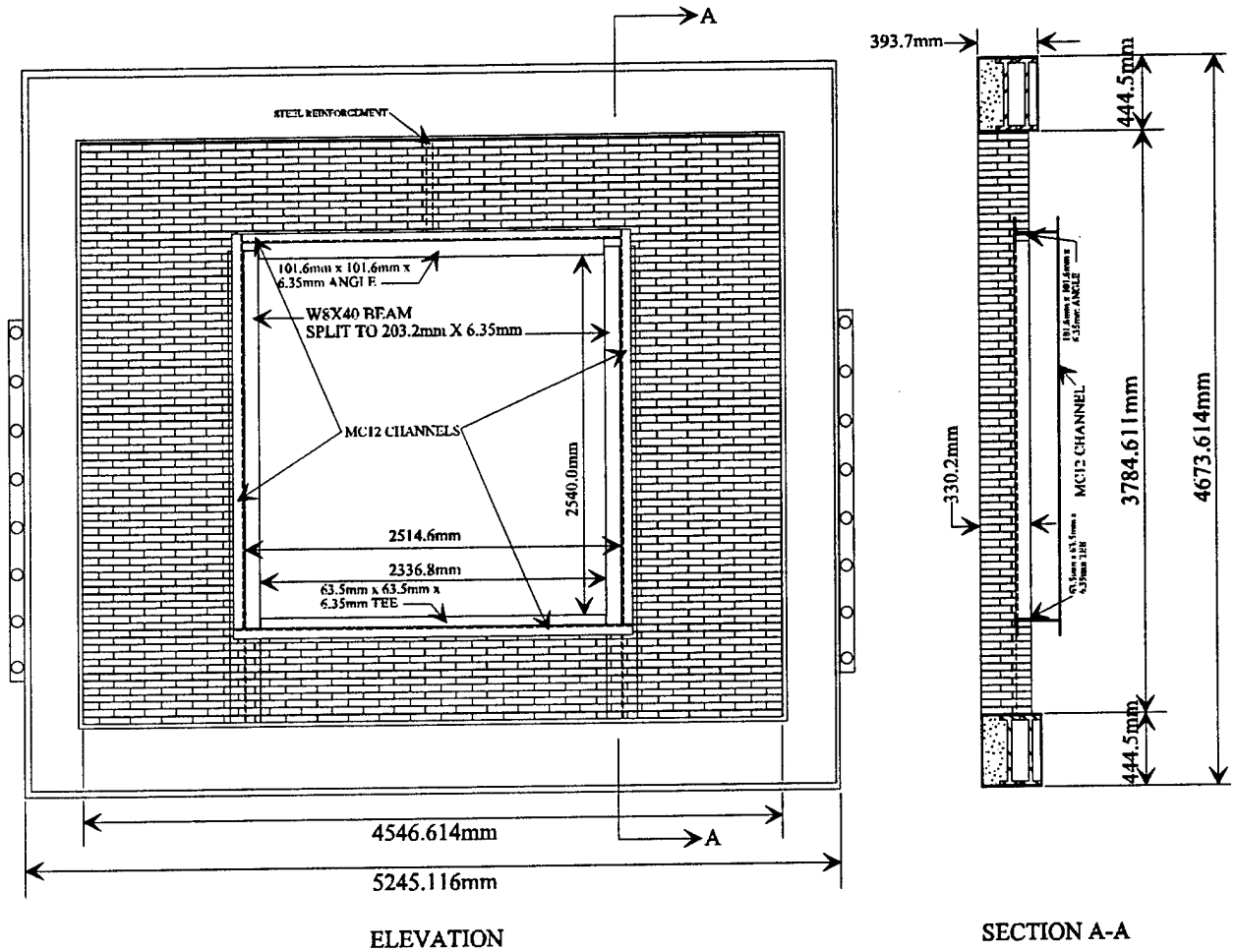
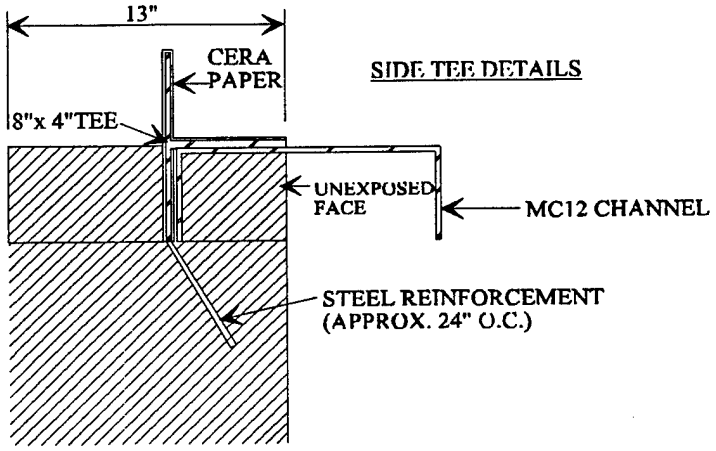
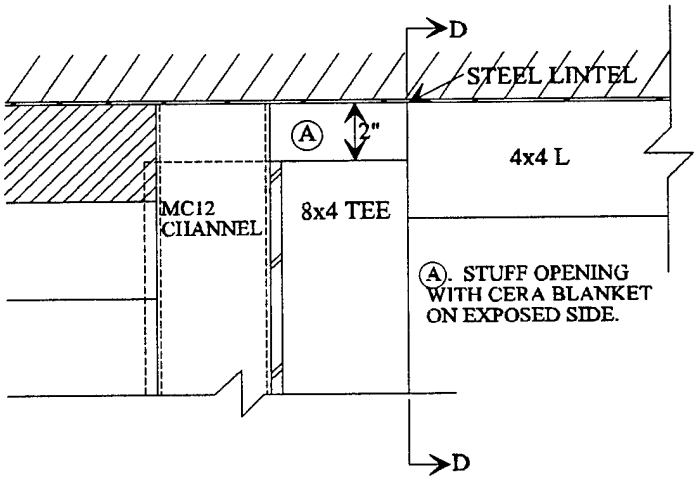


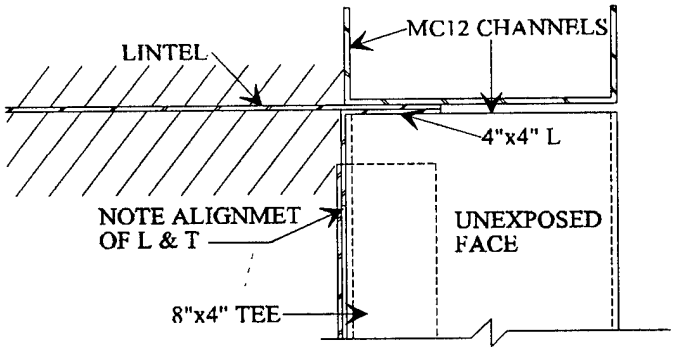
Figure A-3. Test Wall Assembly



SECTION B-B : TOP VIEW



REAR VIEW : SECTION C-C



SECTION D-D

Figure A-4. Test Wall Assembly

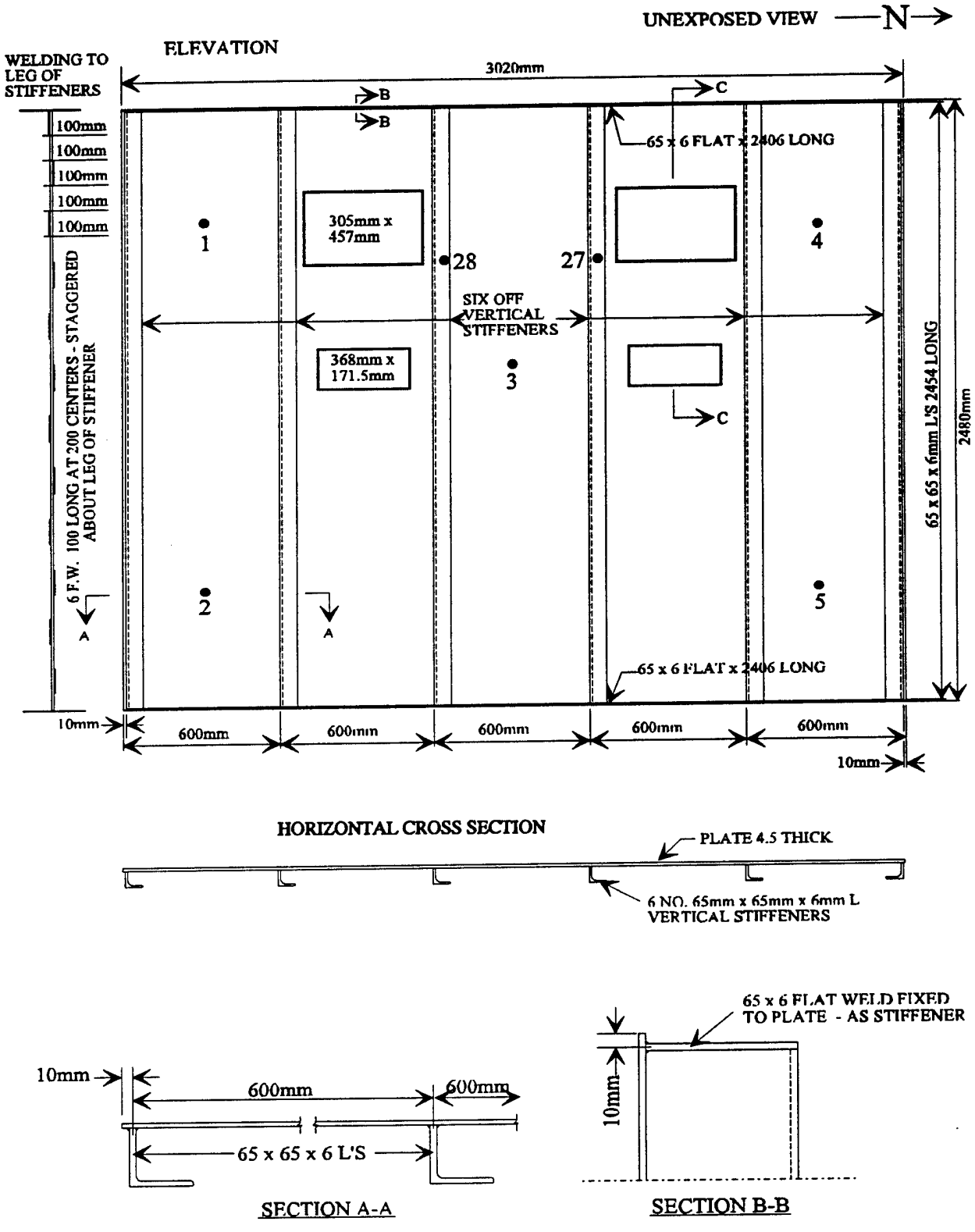


Figure A-5. Bulkhead A

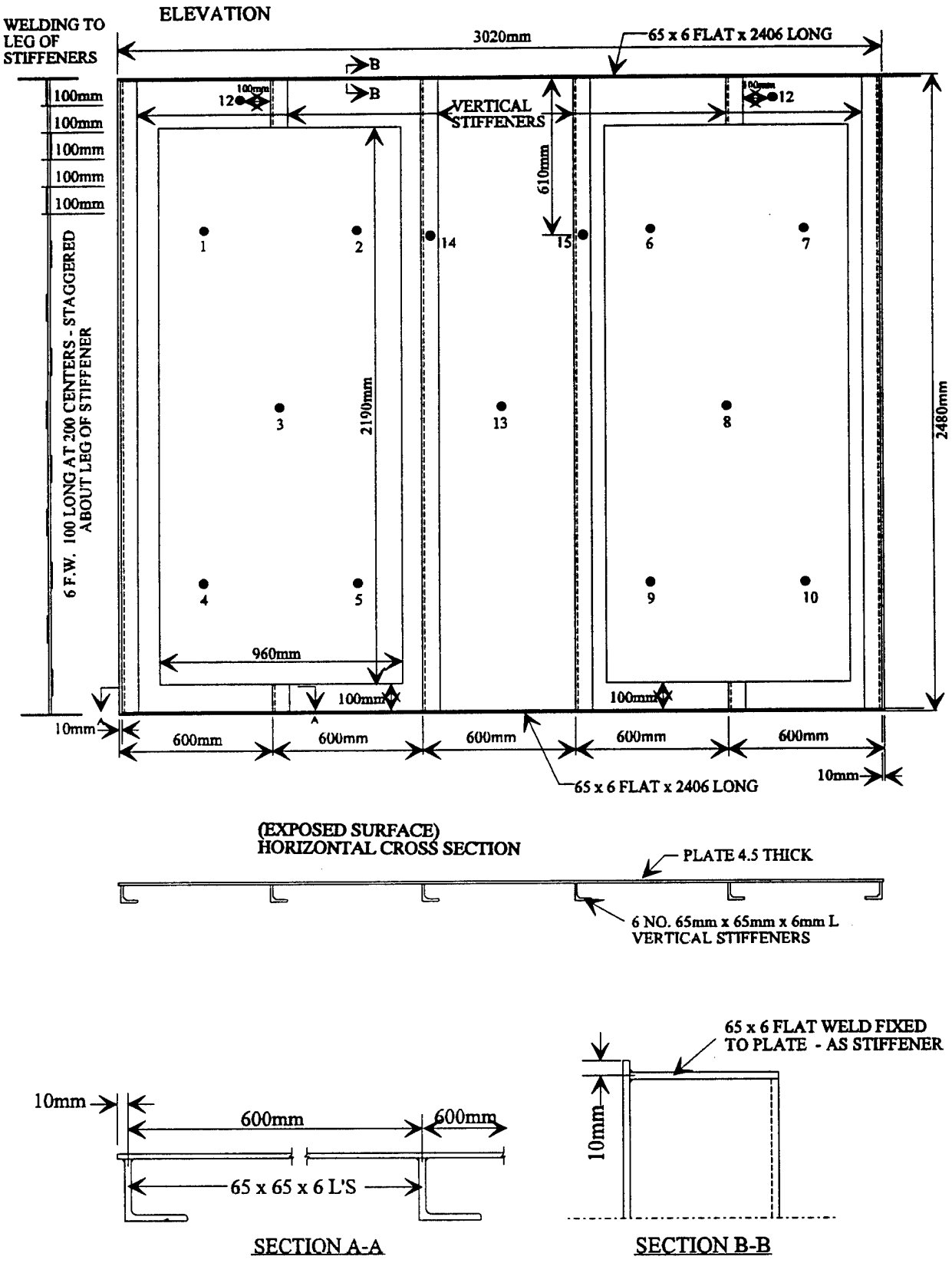


Figure A-6. Bulkheads B through D

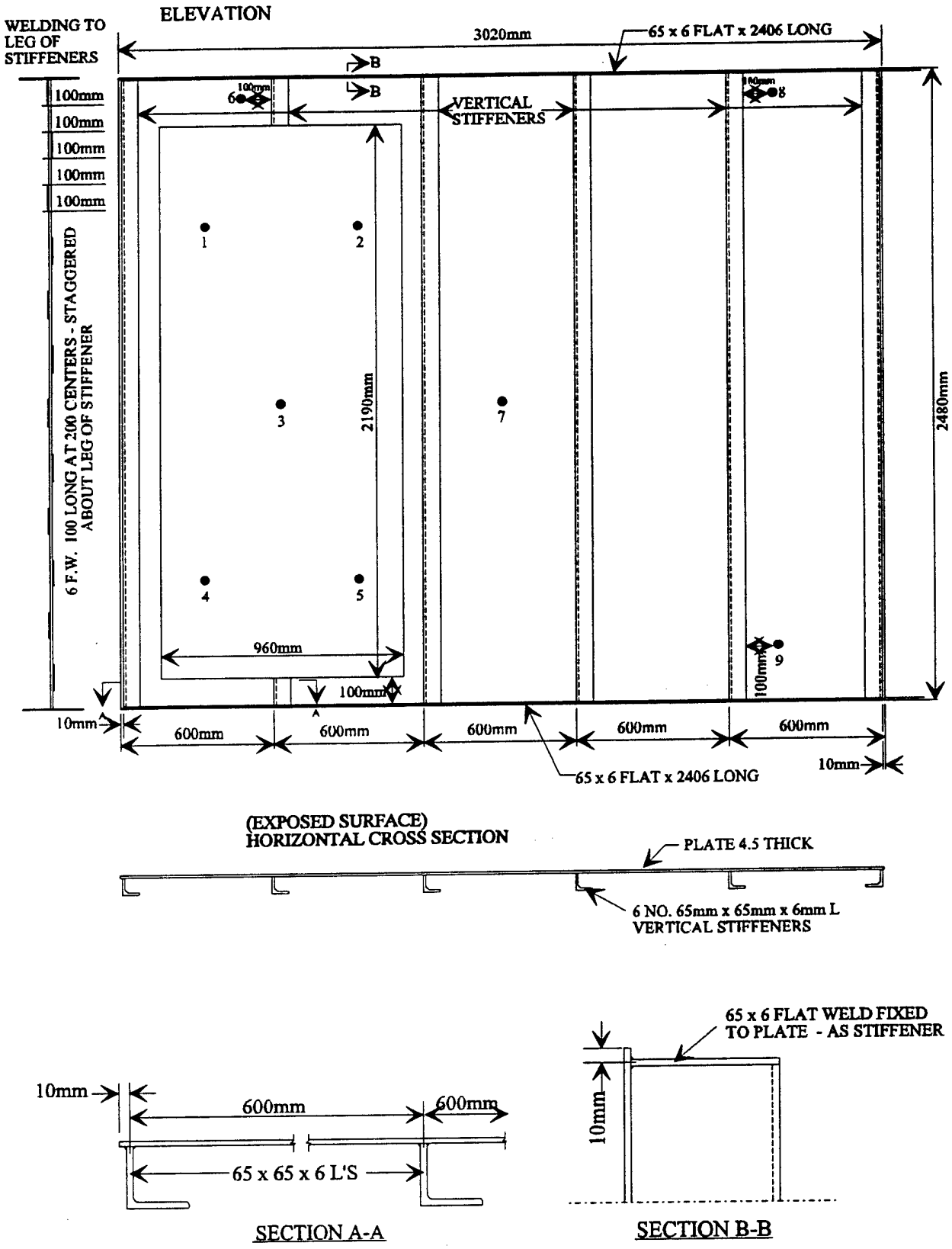


Figure A-7. Bulkhead E

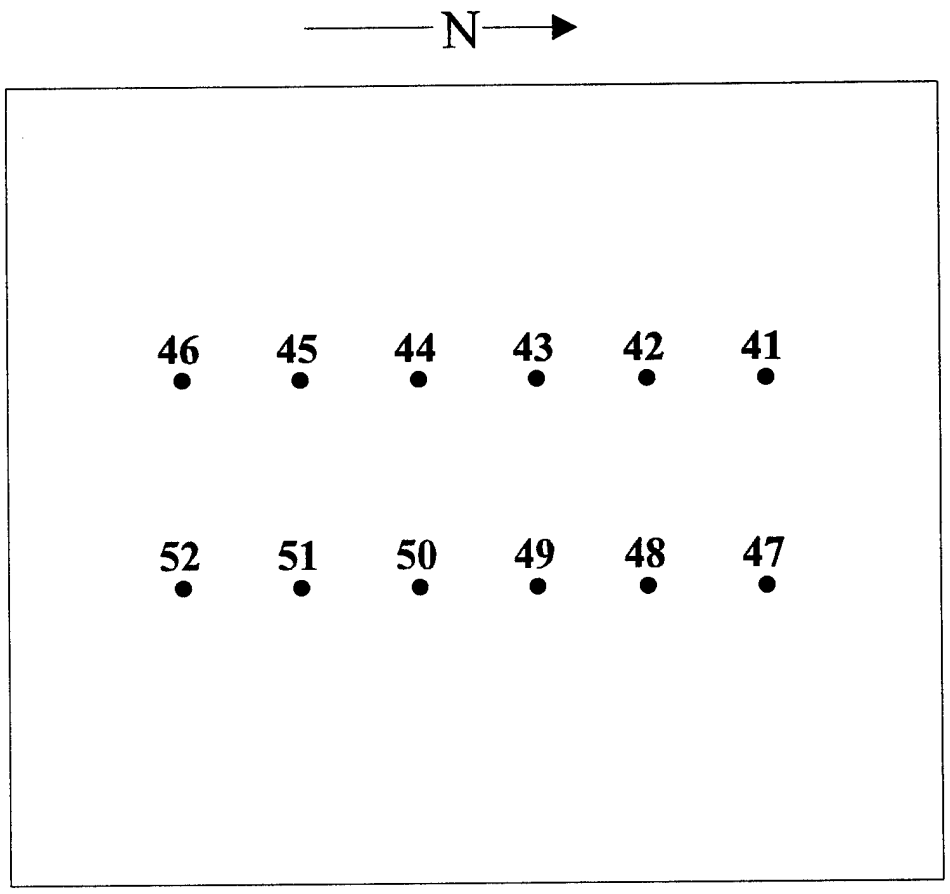
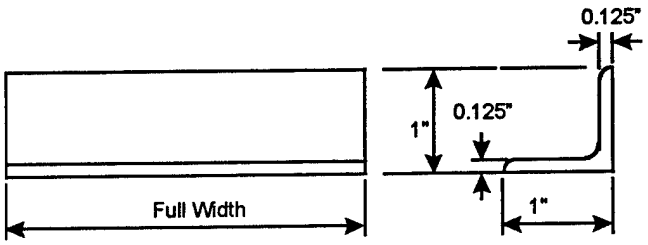
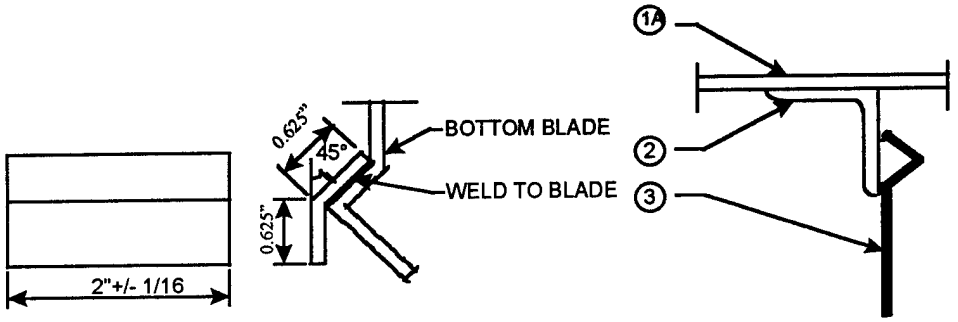


Figure A-8. Furnace Thermocouple Locations



BLADE STOP - ITEM (2)



STRIKER - ITEM (4G)

BLADE CLEARANCE
IN CLOSED POSITION

BILL OF MATERIALS				
PART NO	DESCRIPTION	NO. REQUIRED	MATERIAL	
1A	FRAME	1 PER ASSEMBLY	2"x1/2"x1/8" CHANNEL H.R.	C-1010 STEEL
2	BLADE STOP	2 PER ASSEMBLY	1"x1"x1/8" ANGLE H.R.	C-1010 STEEL
3	BLADE	1 PER ASSEMBLY	12 GA H.R.	C-1010 STEEL
4	BLADE CATCH	1 PER ASSEMBLY	.063 S.S. ½ HARD	T-301 SS
4D	BLADE CATCH MOUNT	1 PER ASSEMBLY	2"x1/2"x1/8" CHANNEL H.R.	C-1010 STEEL
4G	STRIKER	1 PER ASSEMBLY	14 GA. H.R.	C-1010 STEEL
5	FUSIBLE LINK	1 PER ASSEMBLY	VARIOUS	UL LISTED
6	FUSIBLE LINK BRACKET	2 PER ASSEMBLY	1/8"x1/2" H.R.	C-1010 STEEL
7	SPRING	1 PER ASSEMBLY	.54 STAINLESS	T-301 SS
8	SPRING BRACKETS	2 PER ASSEMBLY	16 GA H.R.	C-1010 STEEL
9	BEARING SHAFT	2 PER ASSEMBLY	1/2" DIA. COLD ROLLED	C-1010 STEEL
10	BUSHING	2 PER ASSEMBLY	SINTERED BRONZE	
11	BEARING STRAP W/¼"-28x½" SET SCREW	2 PER ASSEMBLY	1/8"x1" HOT ROLLED	C-1010 STEEL
18	SLEEVE	1 PER ASSEMBLY	16 GA H.R.	C-1010 STEEL
19B	MOUNTING ANGLE	8 PER ASSEMBLY	1-1/2"x1-1/2"x18 ga.	C-1010 STEEL

Figure A-9. Damper Construction (Sample 1)

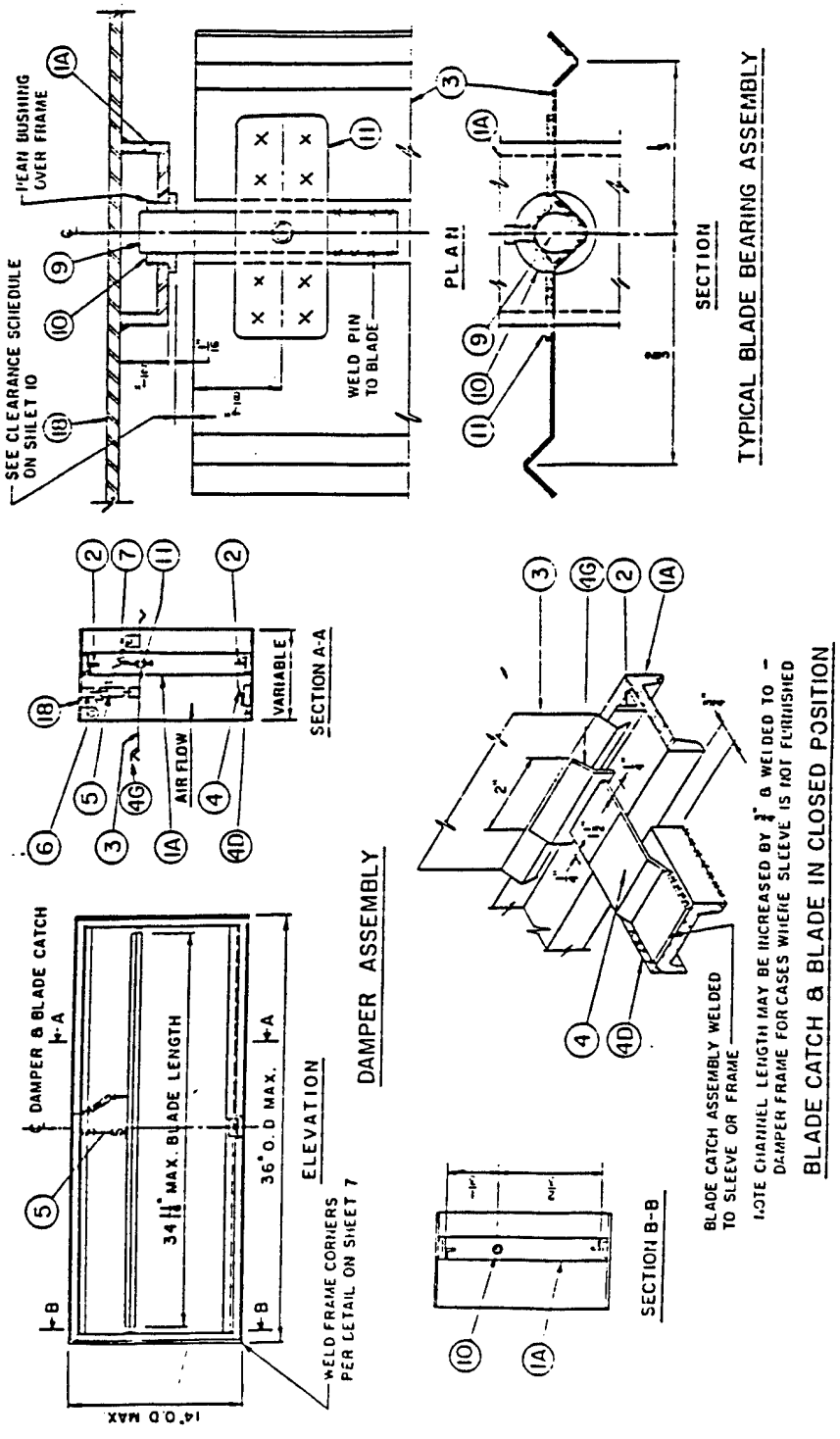


Figure A-10. Damper Construction (Sample 1)

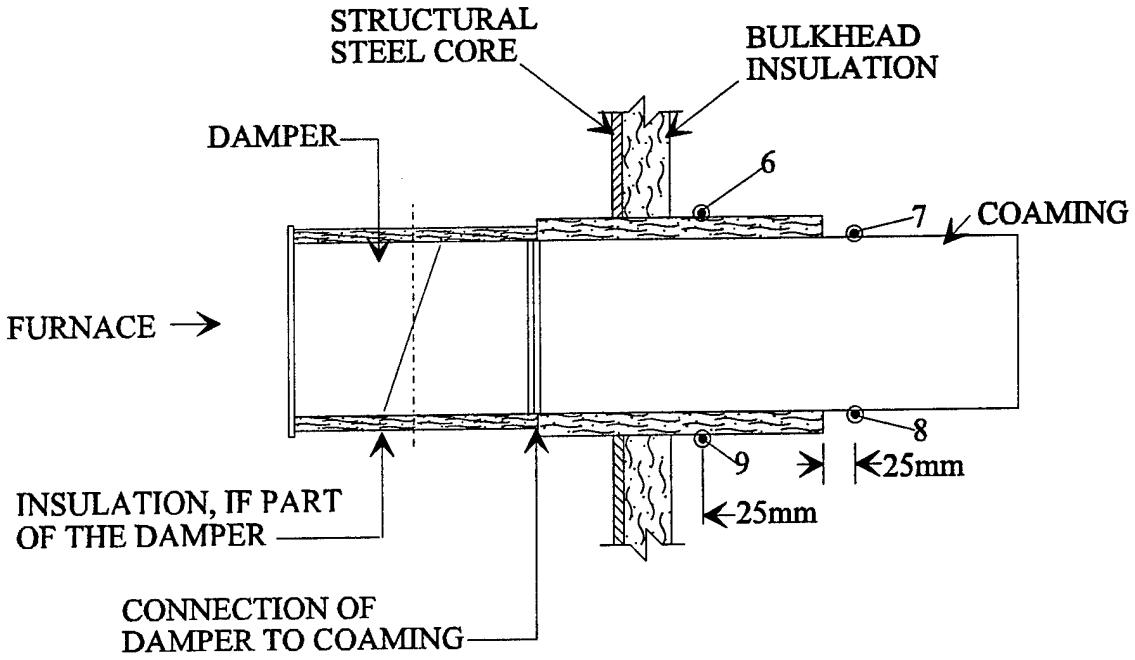


Figure A-11. Damper Thermocouple Locations (Sample 1)

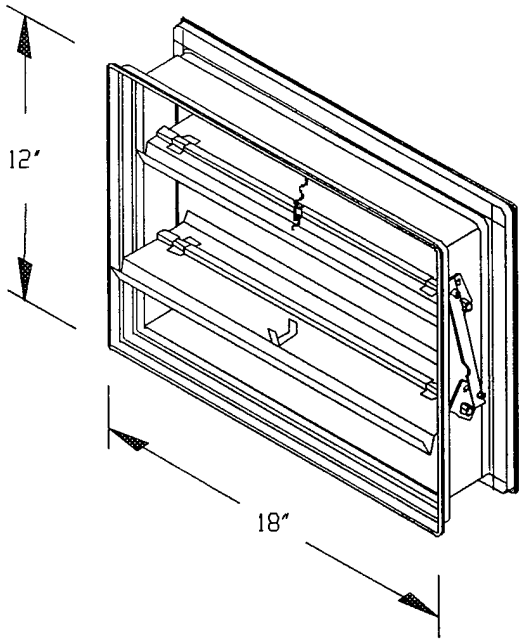


Figure A-12. Damper Schematic (Sample 2)

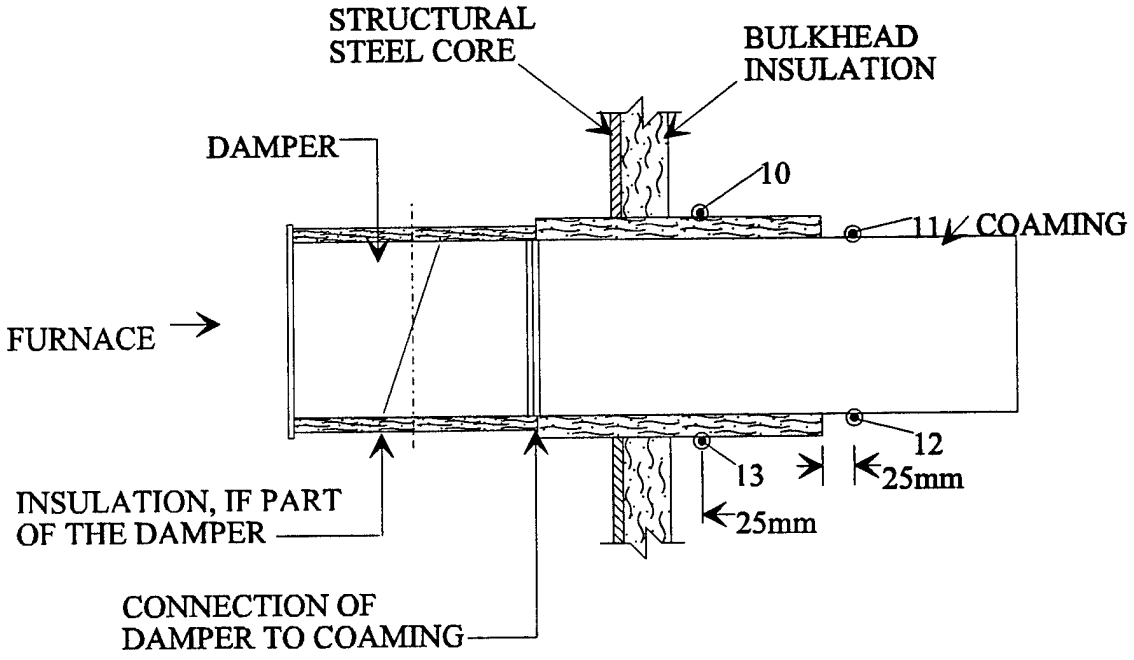


Figure A-13. Damper Thermocouple Locations (Sample 2)

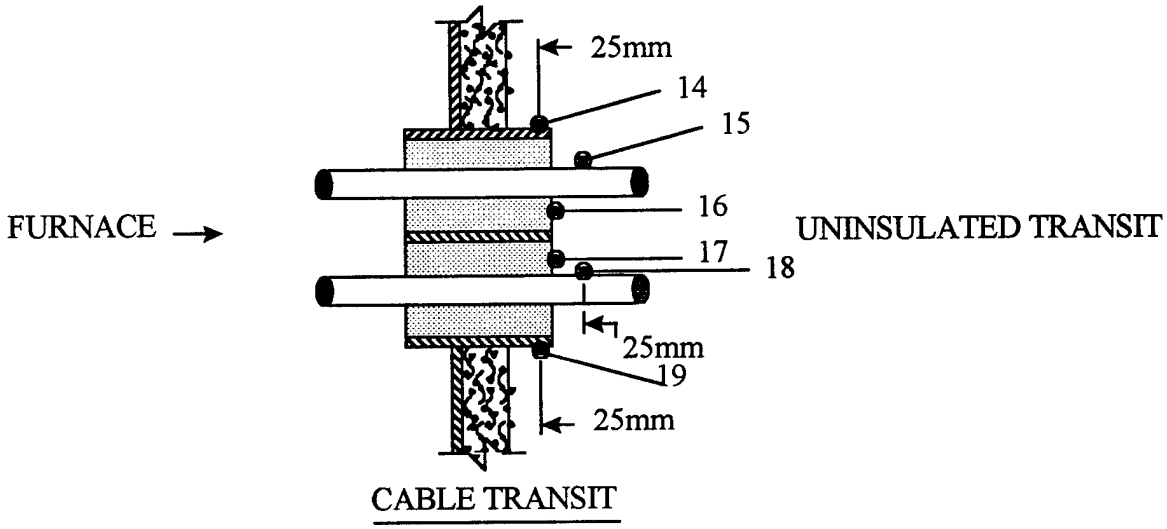


Figure A-14. Fire Stop Thermocouple Locations (Sample 3)

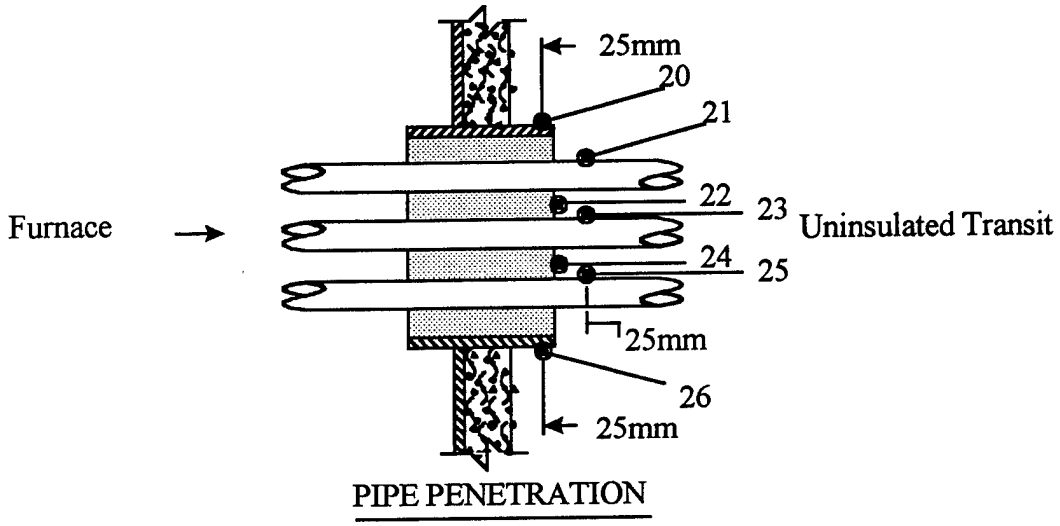


Figure A-15. Fire Stop Thermocouple Locations (Sample 4)

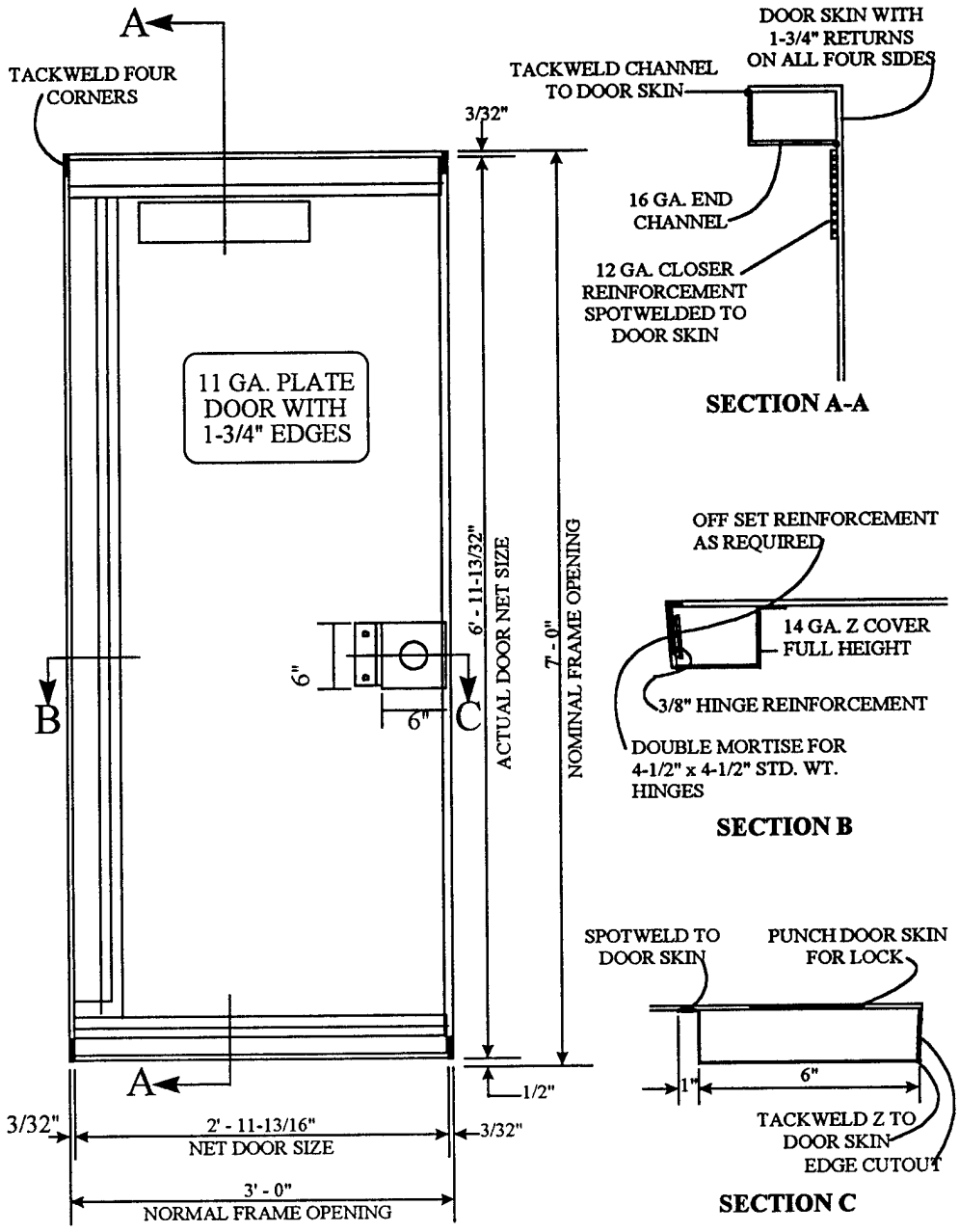


Figure A-16. Door Construction: Sample 5

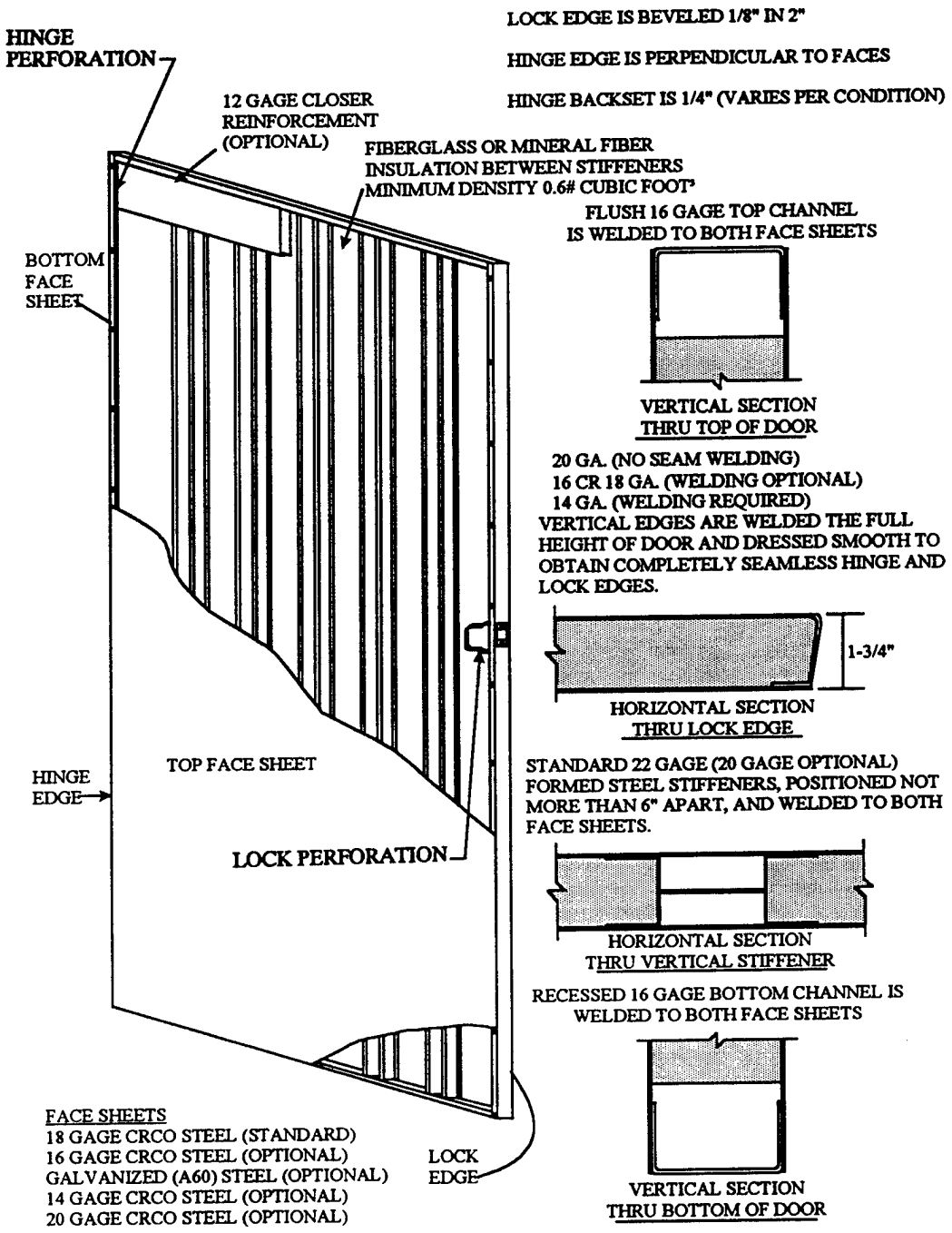


Figure A-17. Door Construction: Samples 7, 8, and 10

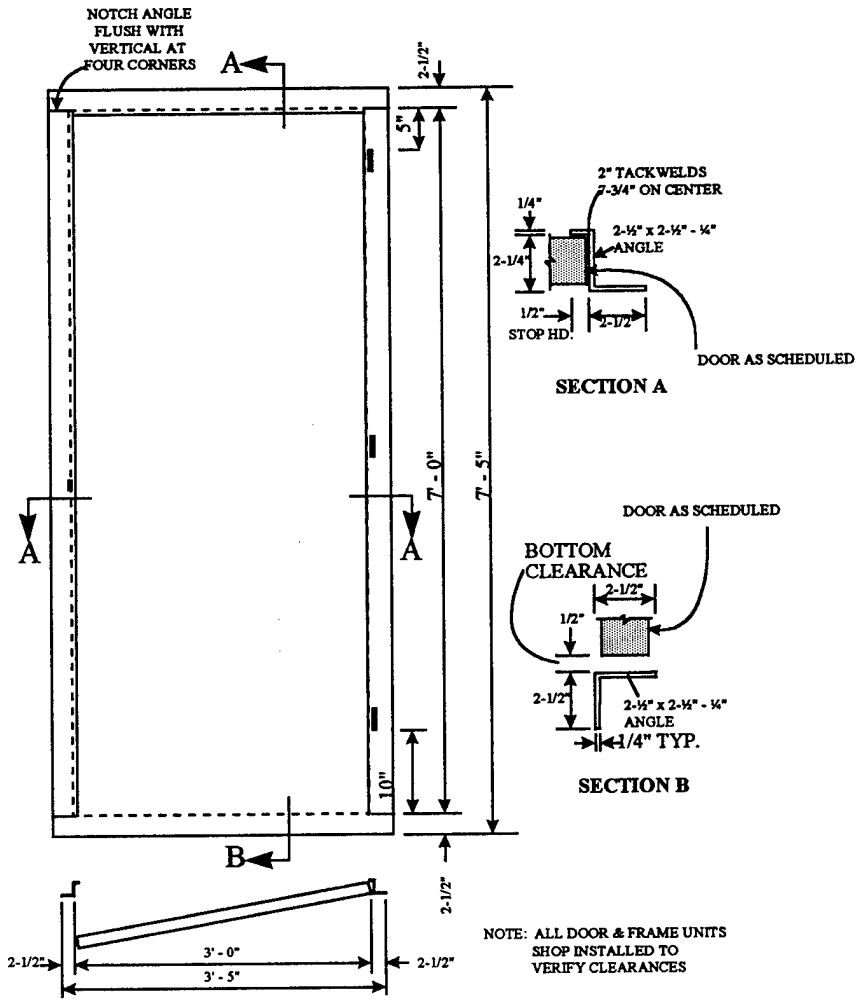


Figure A-18. Door Construction: Samples 6, 9 and 11

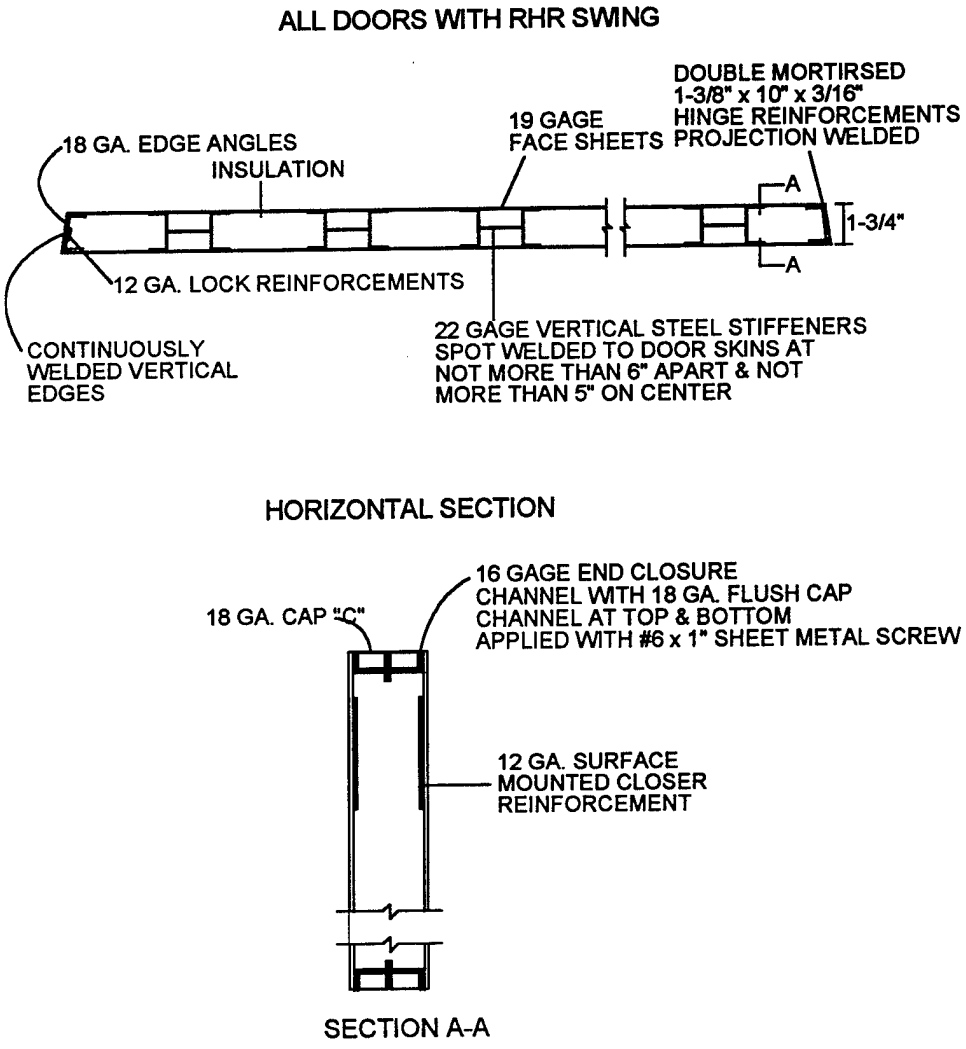


Figure A-19. Door Construction: Samples 6, 9 and 11

Appendix B
Calibration Information

Table B-1. Laminar Flow Element Specification

No.	Diameter (mm)	Model	Maximum Flow Range*	Calibration
1	51	50MC2 2	175 m^3/h	Figure B-1
2	152	50MC2 6	1850 m^3/h	Figure B-2

* measured at 21°C and 3989 Pa

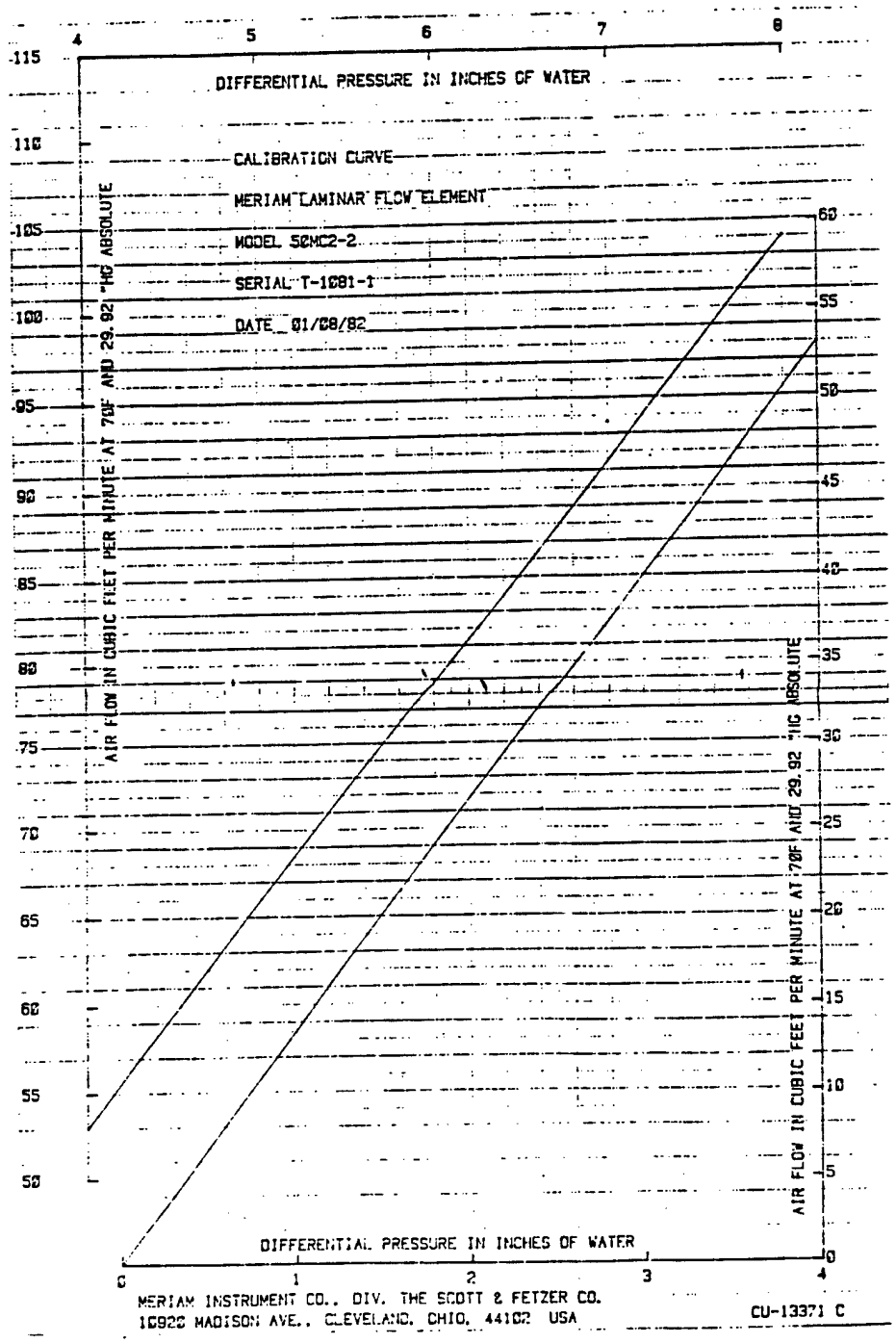


Figure B-1. Laminar Flow Element Calibration Sheet

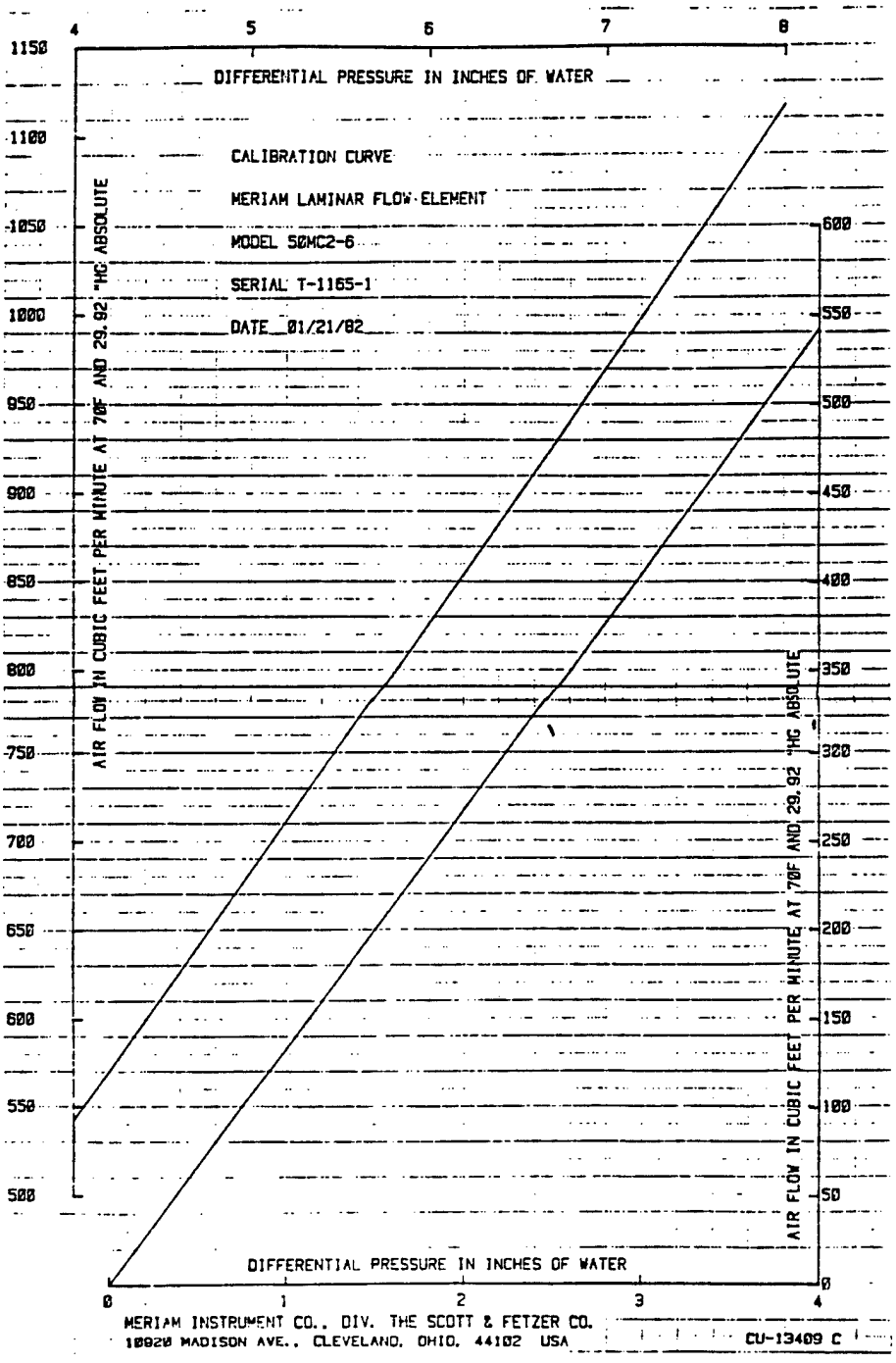


Figure B-2. Laminar Flow Element Calibration Sheet

Appendix C
Fire Test - Furnace Results

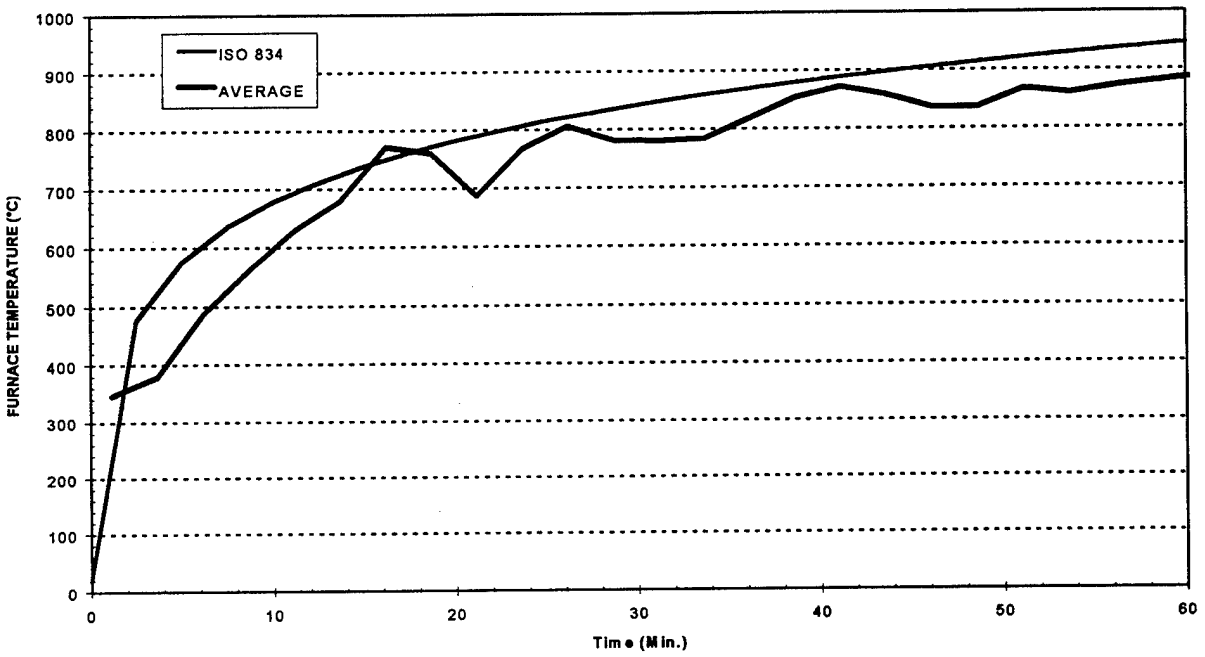


Figure C-1. Time-Temperature Curve for Bulkhead A

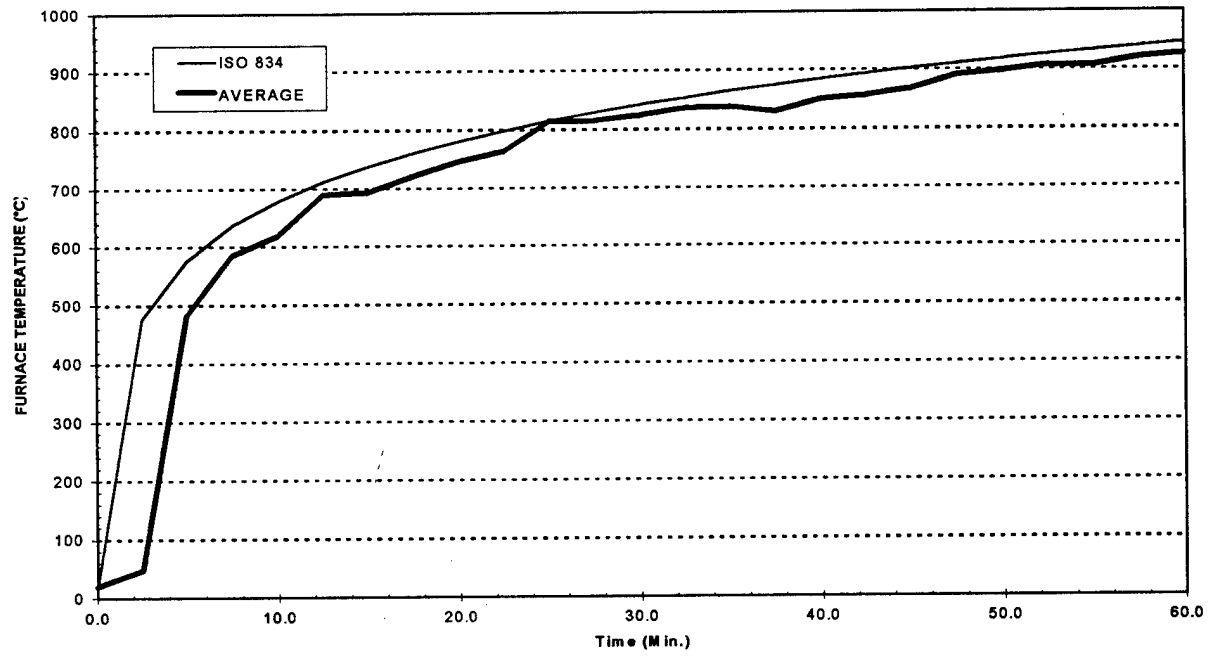


Figure C-2. Time-Temperature Curve for Bulkhead B

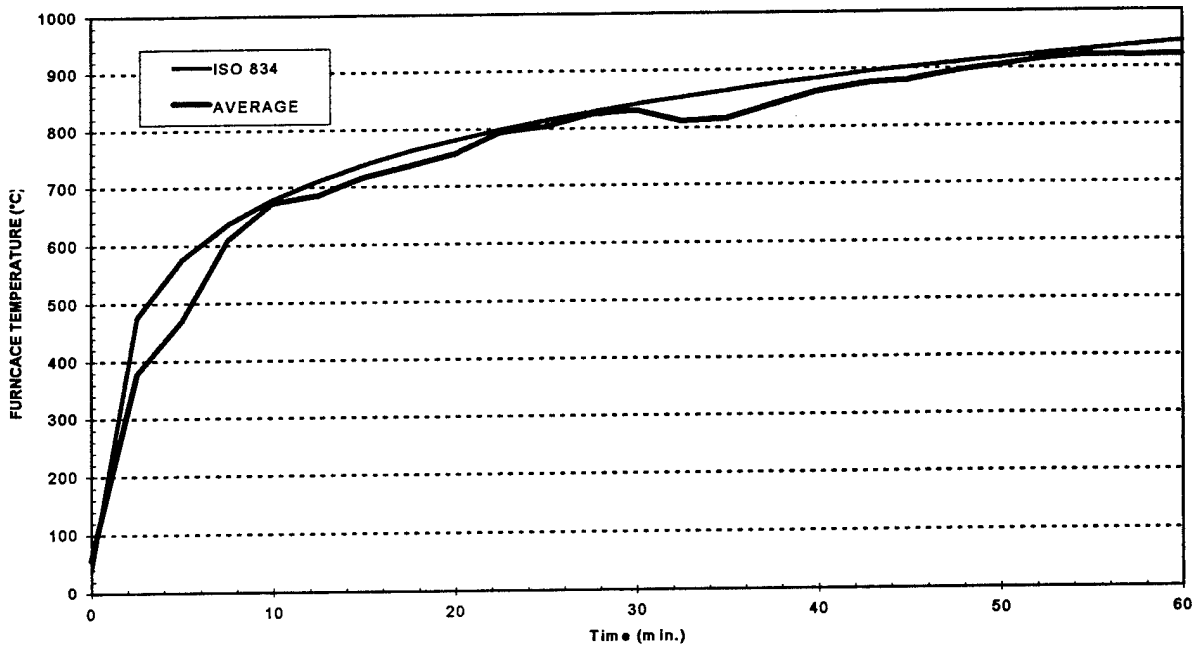


Figure C-3. Time-Temperature Curve for Bulkhead C

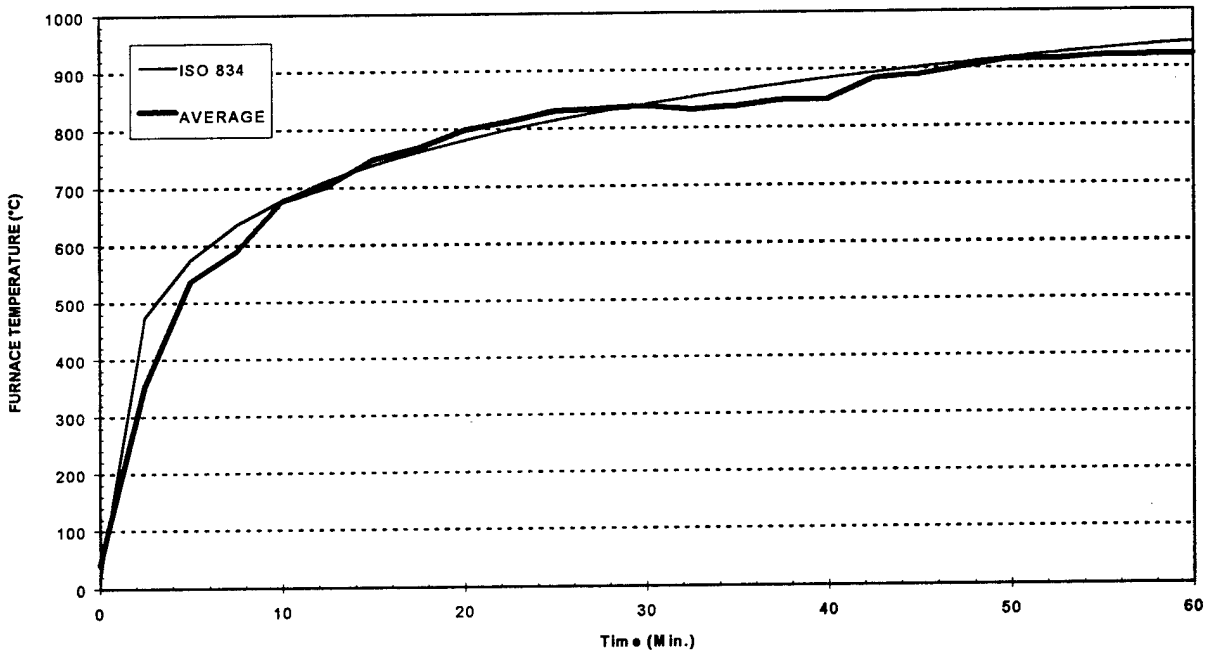


Figure C-4. Time-Temperature Curve for Bulkhead D

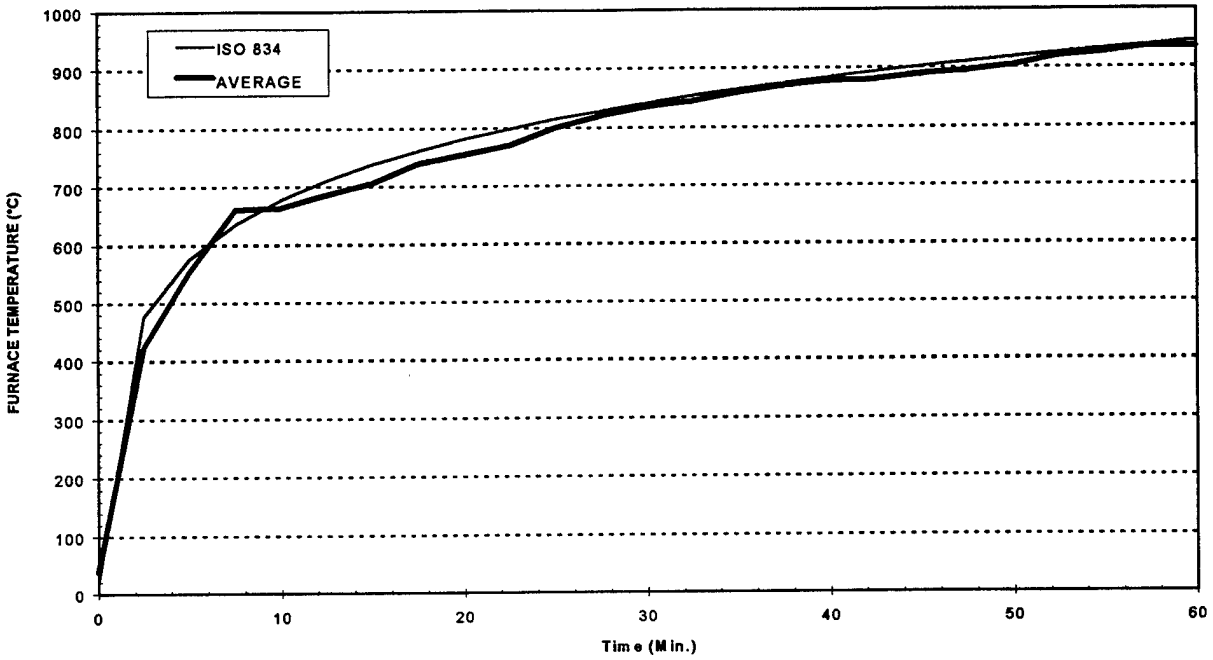


Figure C-5. Time-Temperature Curve for Bulkhead E

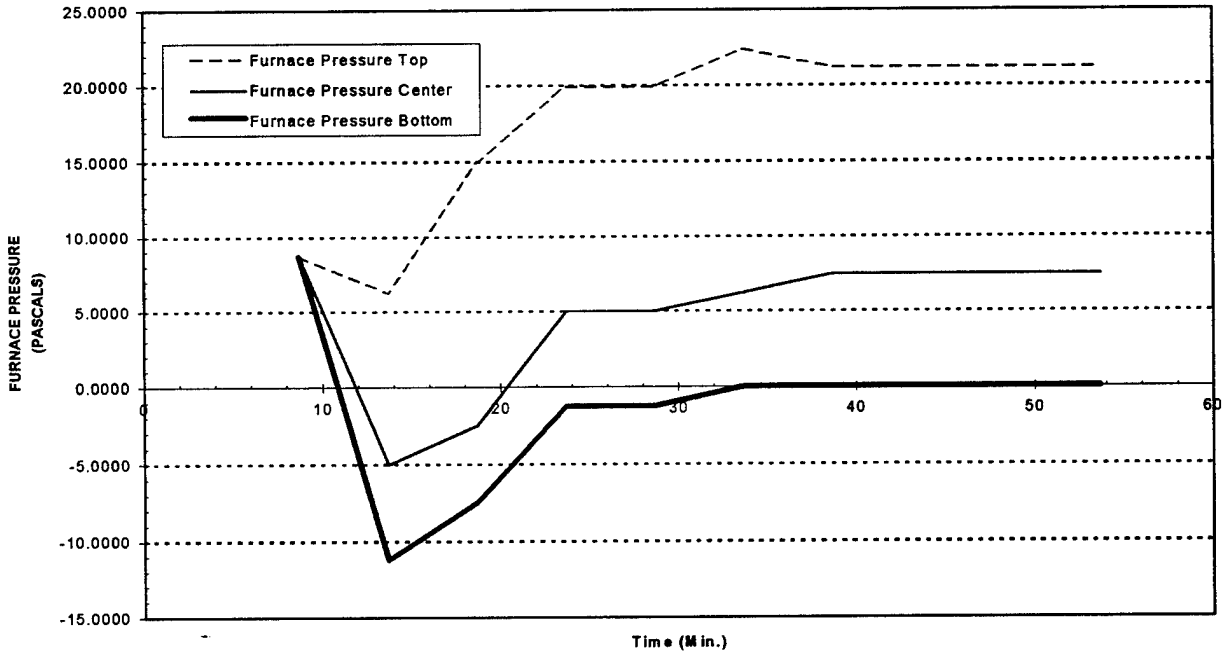


Figure C-6. Furnace Pressures for Bulkhead A

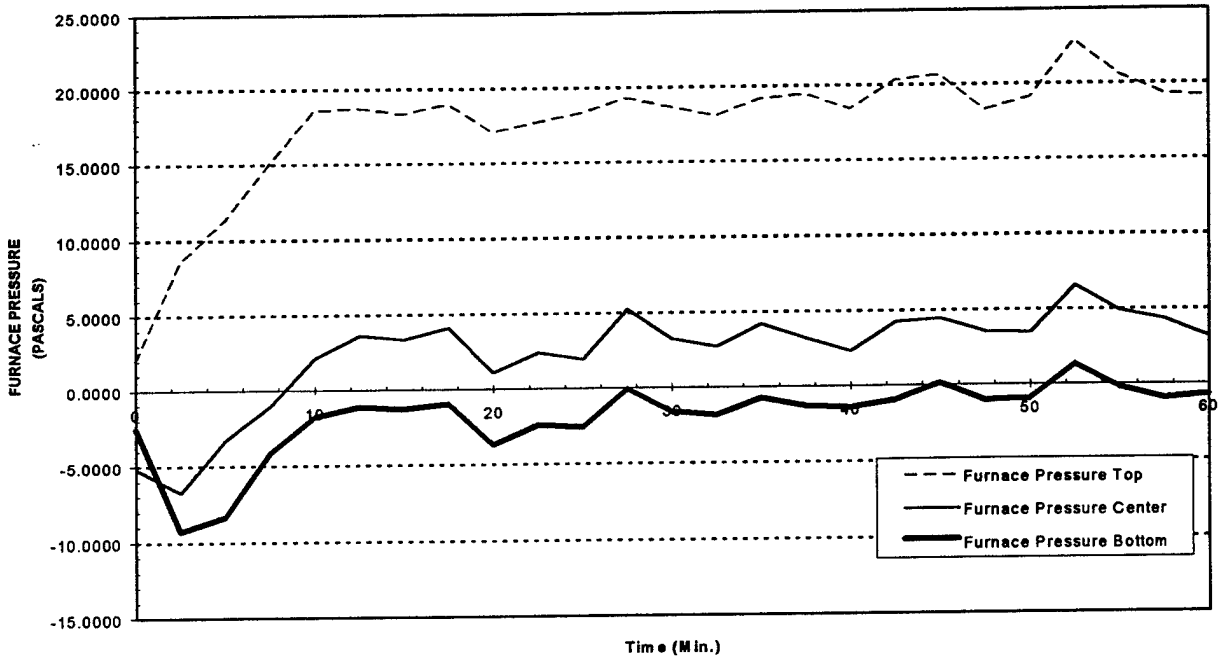


Figure C-7. Furnace Pressures for Bulkhead B

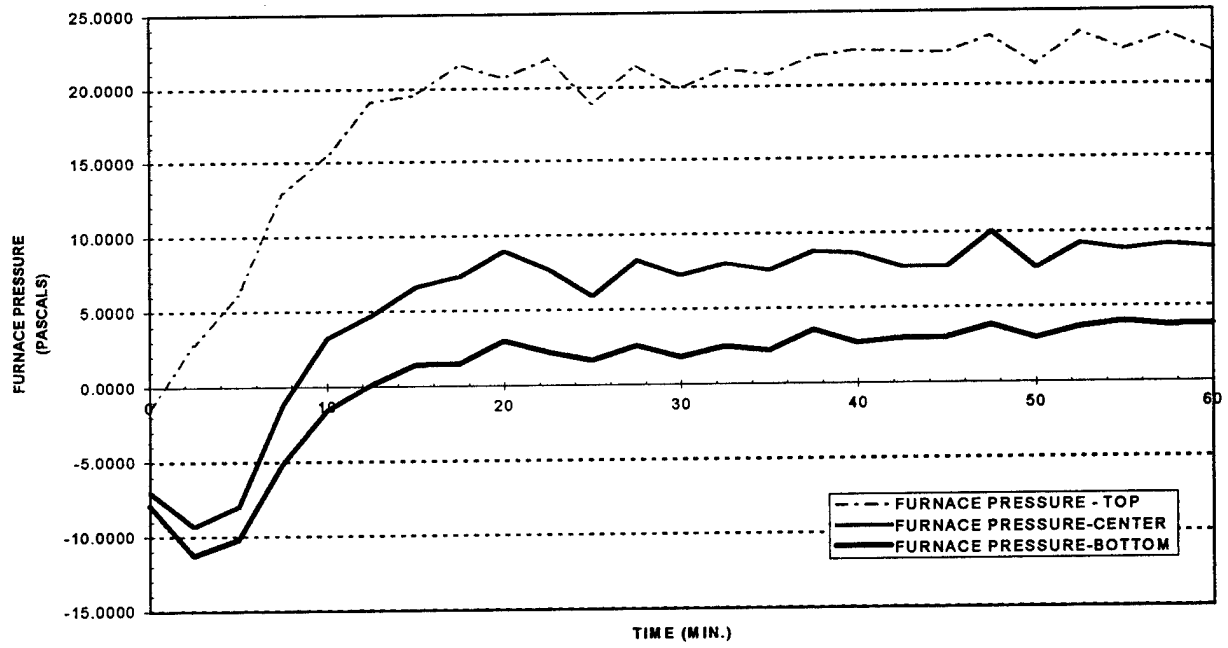


Figure C-8. Furnace Pressures for Bulkhead C

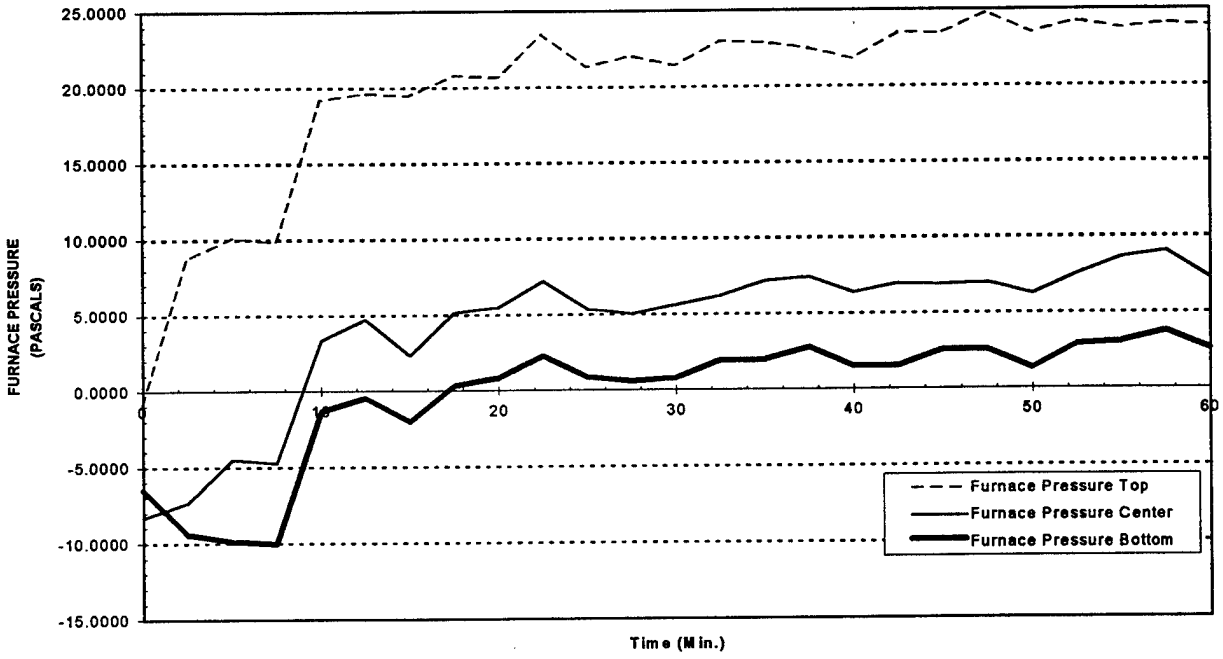


Figure C-9. Furnace Pressures for Bulkhead D

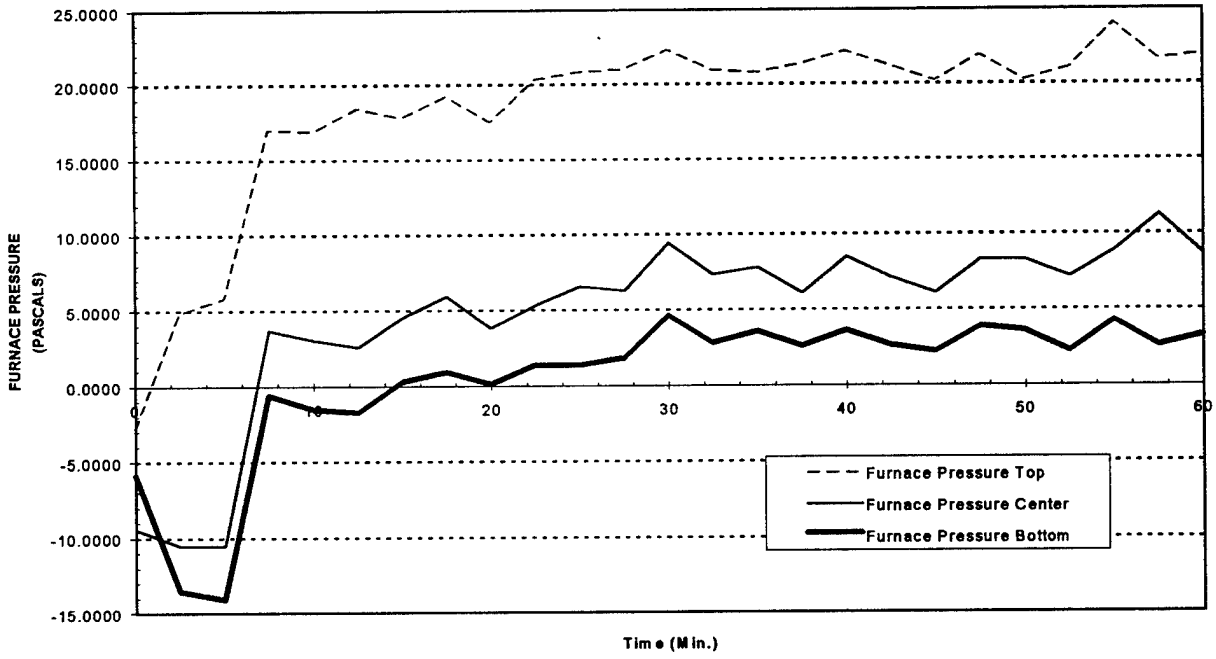


Figure C-10. Furnace Pressures for Bulkhead E

Appendix D
Fire Test - Unexposed Surface Temperatures

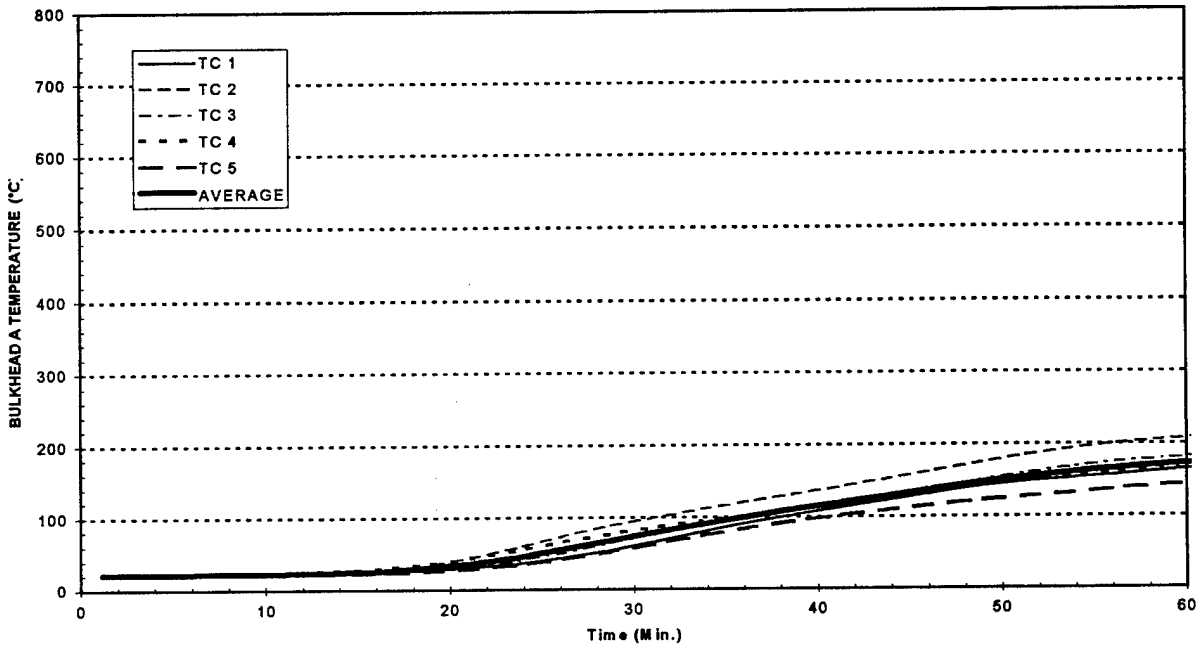


Figure D-1. Unexposed Surface Temperature: Bulkhead A

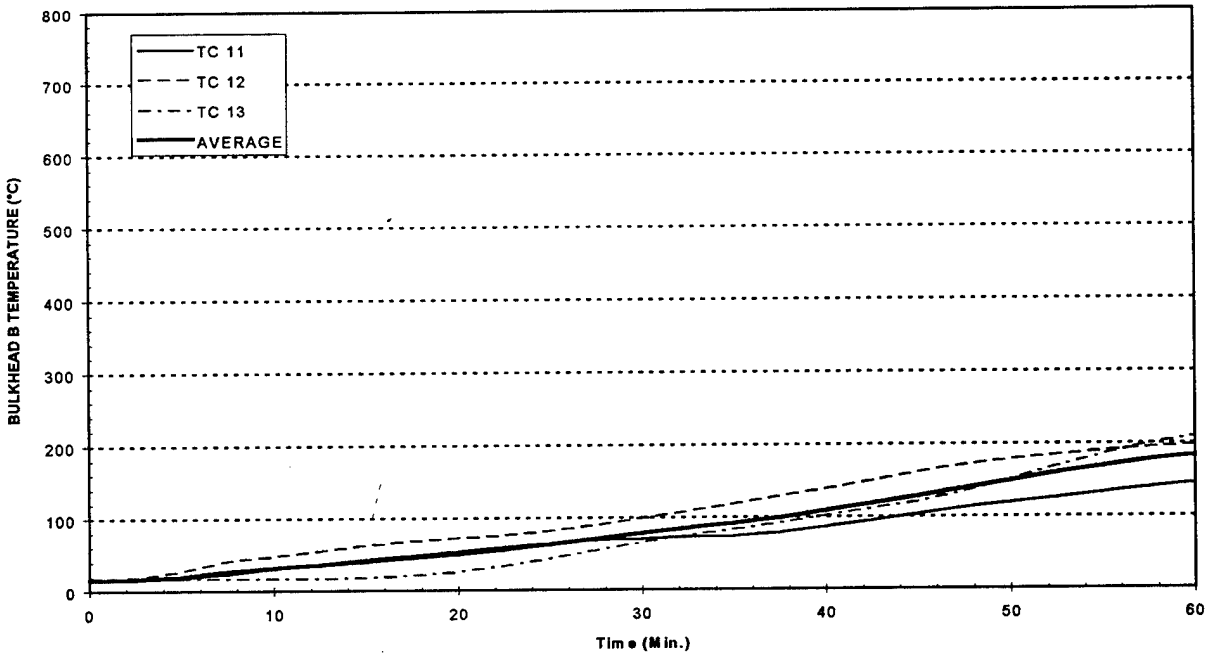


Figure D-2. Unexposed Surface Temperature: Bulkhead B

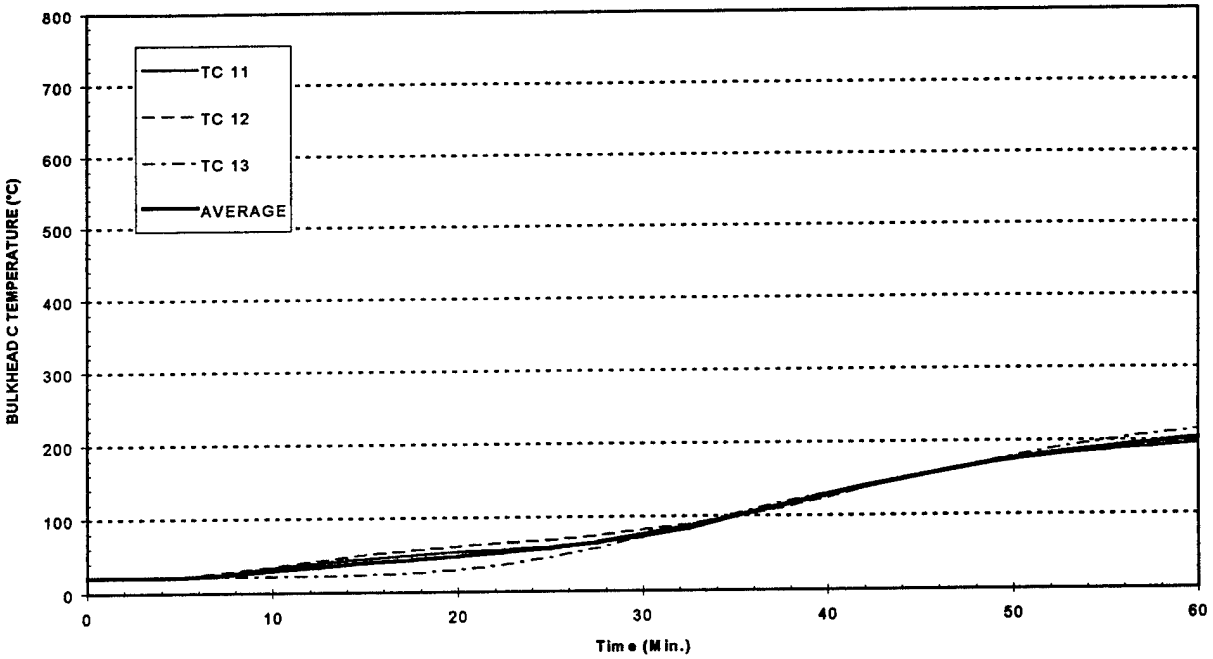


Figure D-3. Unexposed Surface Temperature: Bulkhead C

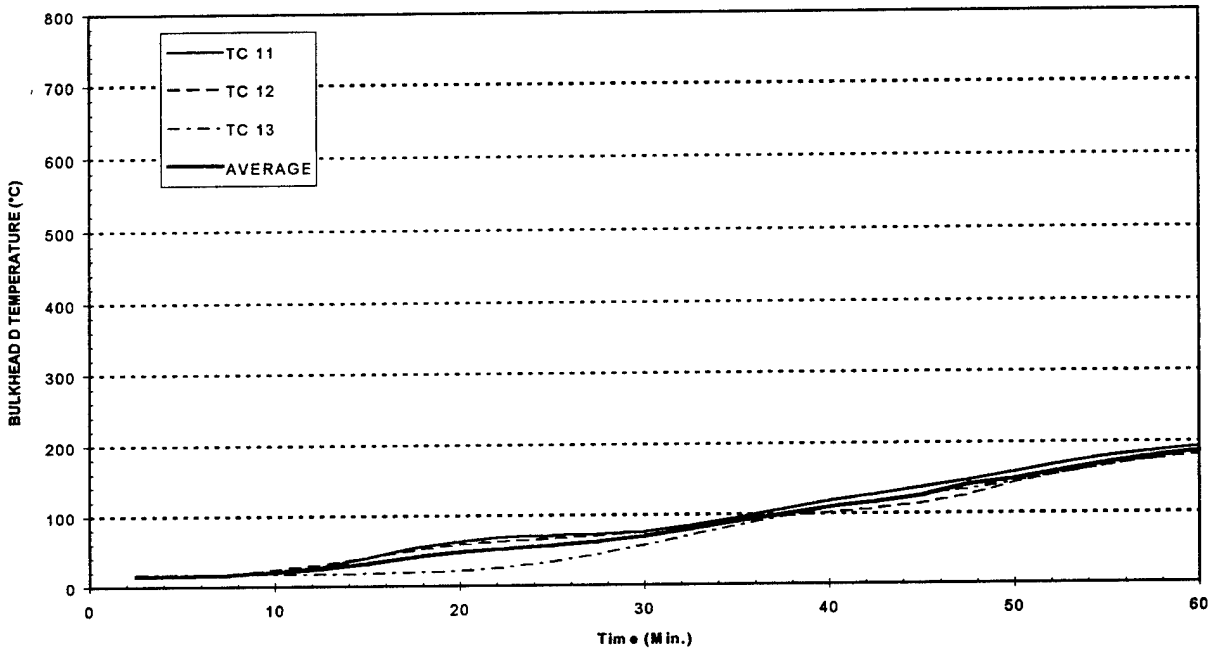


Figure D-4. Unexposed Surface Temperature: Bulkhead D

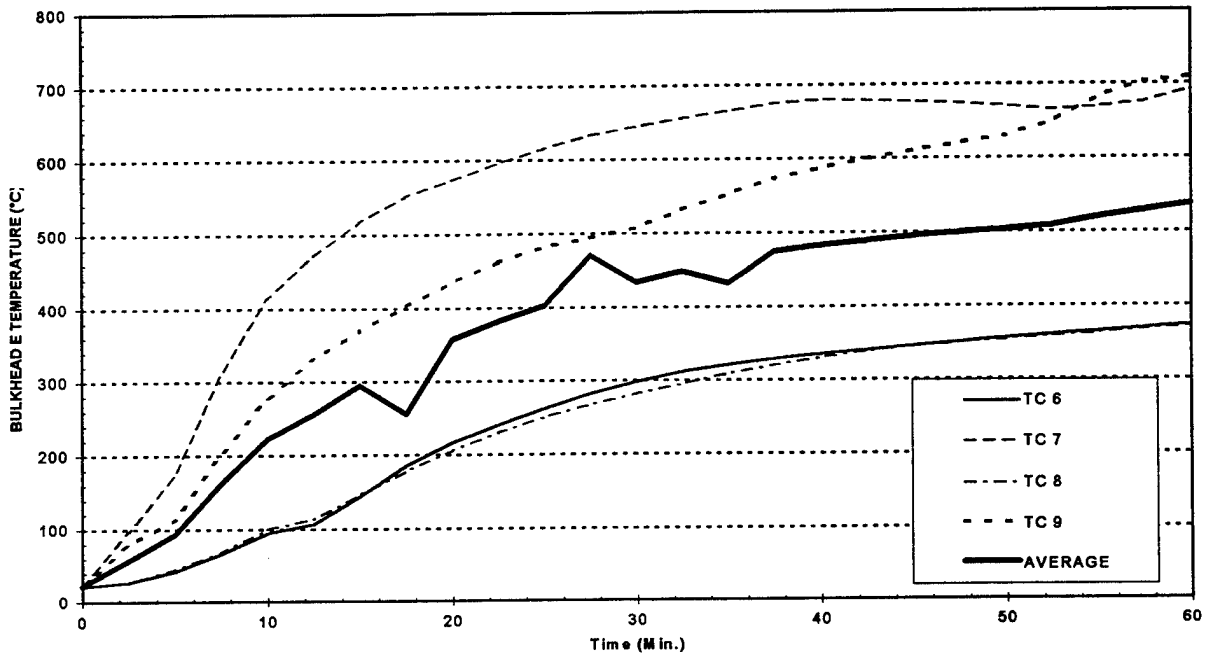


Figure D-5. Unexposed Surface Temperature: Bulkhead E

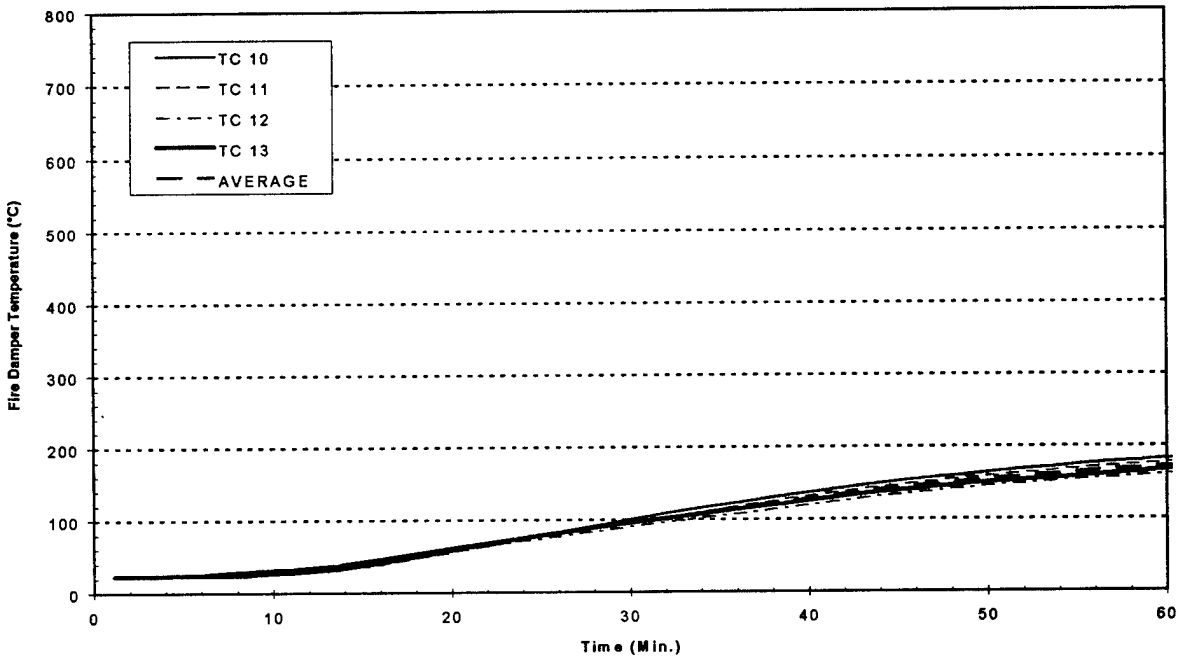


Figure D-6. Unexposed Surface Temperature: Fire Damper (Sample 1)

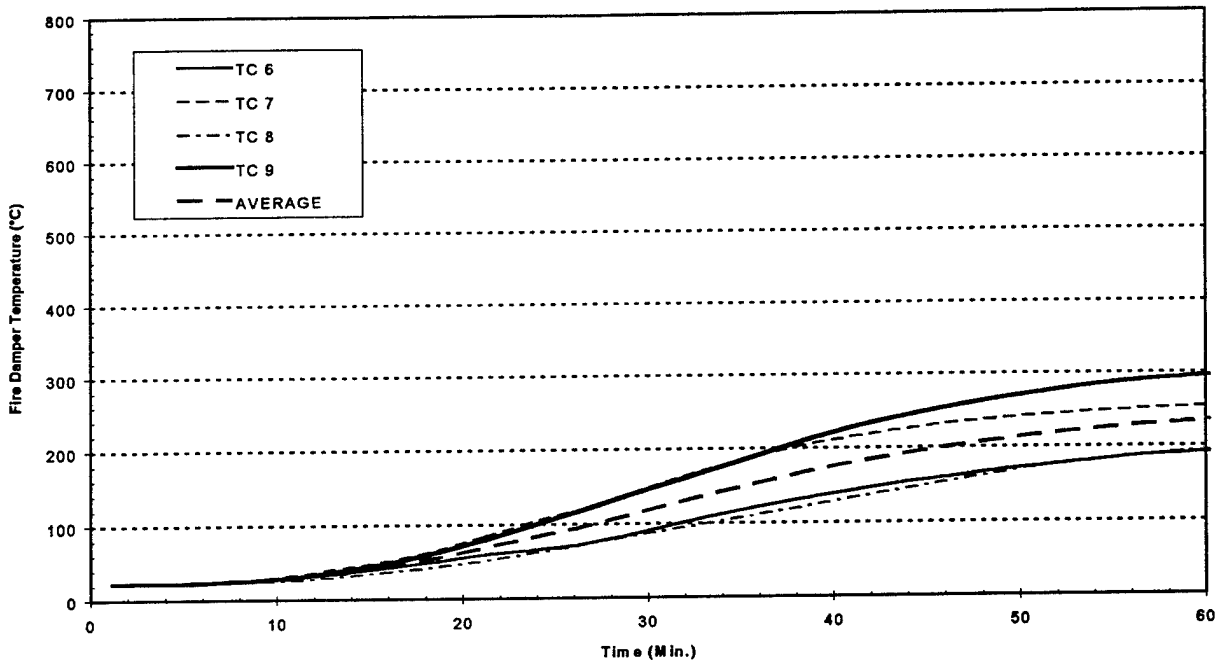


Figure D-7. Unexposed Surface Temperature: Fire Damper (Sample 2)

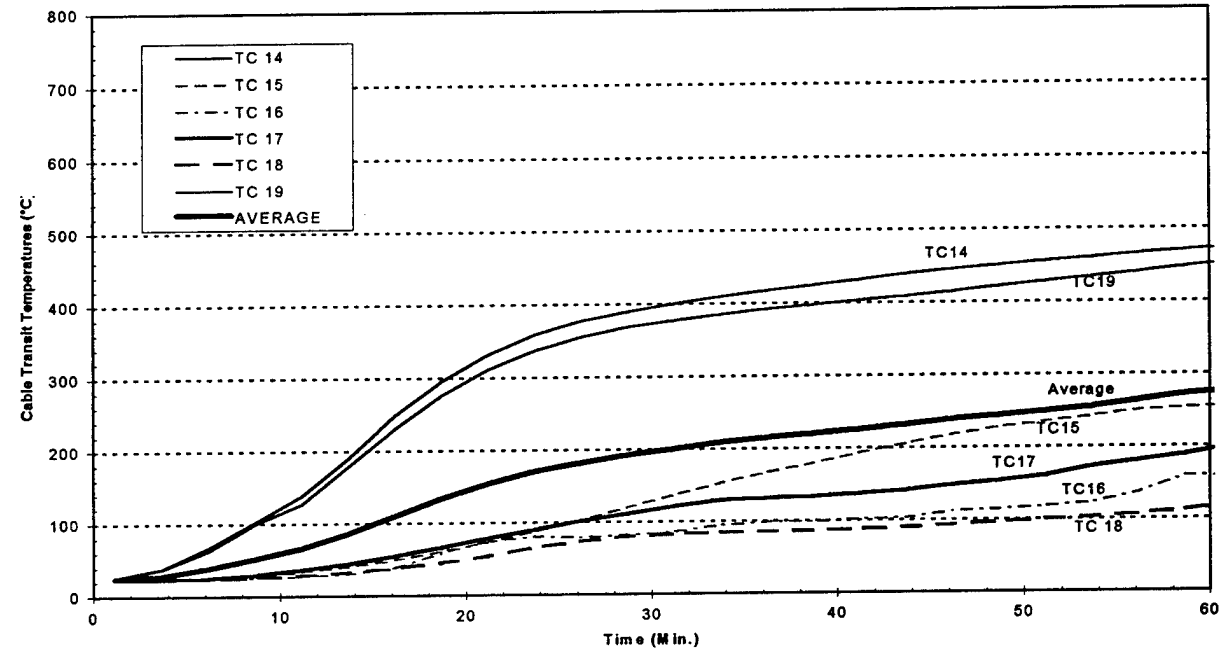


Figure D-8. Unexposed Surface Temperature: Fire Stop (Sample 3)

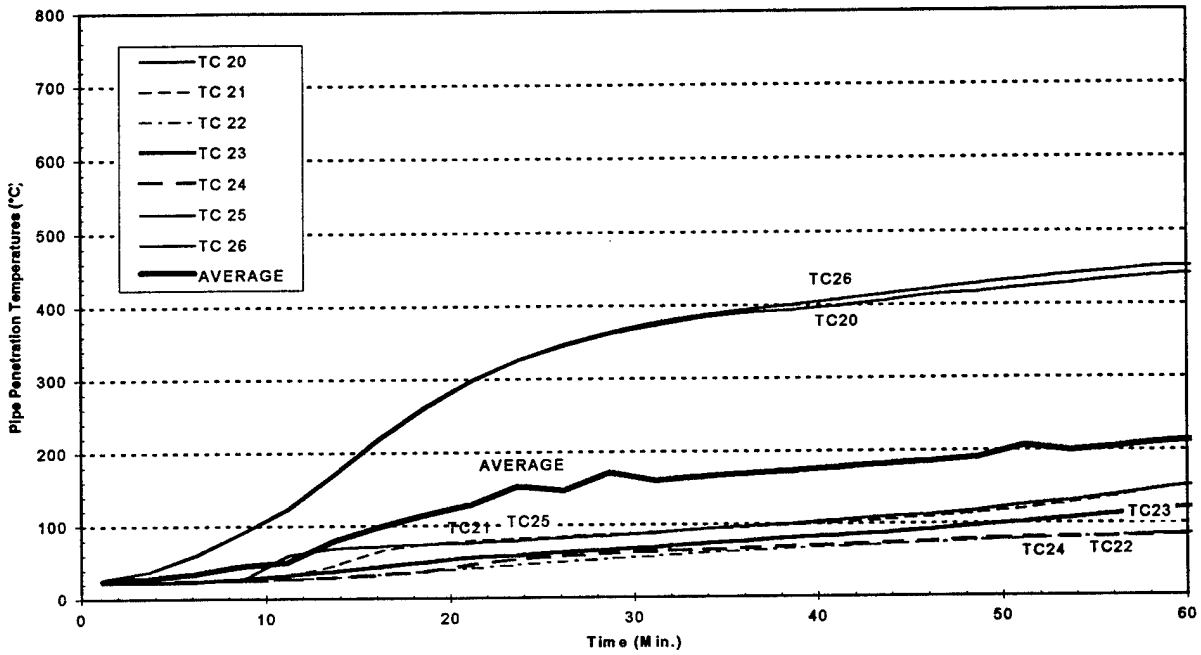


Figure D-9. Unexposed Surface Temperature: Fire Stop (Sample 4)

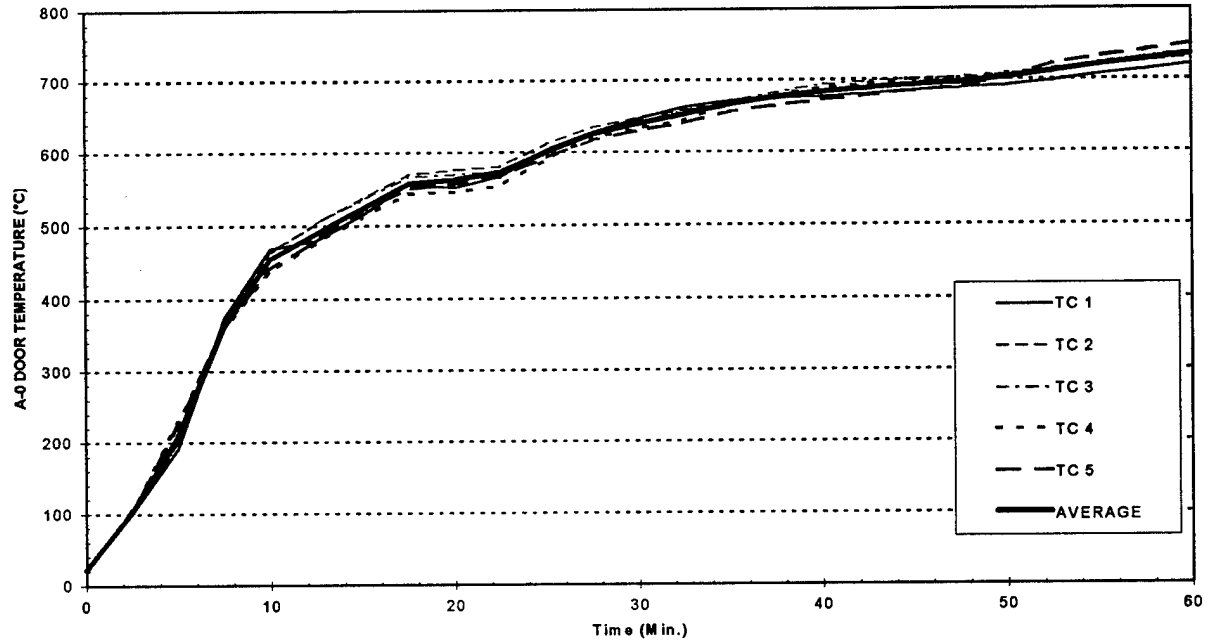


Figure D-10. Unexposed Surface Temperature: A-0 Fire Door (Sample 5)

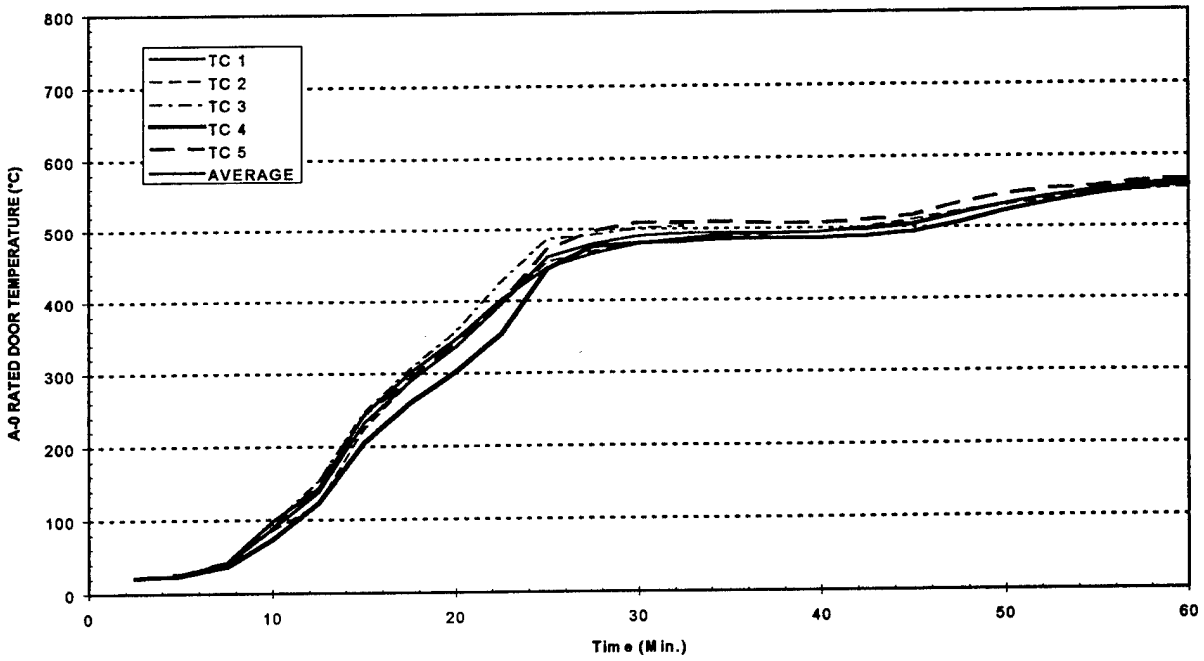


Figure D-11. Unexposed Surface Temperature: A-0 Fire Door (Sample 6)

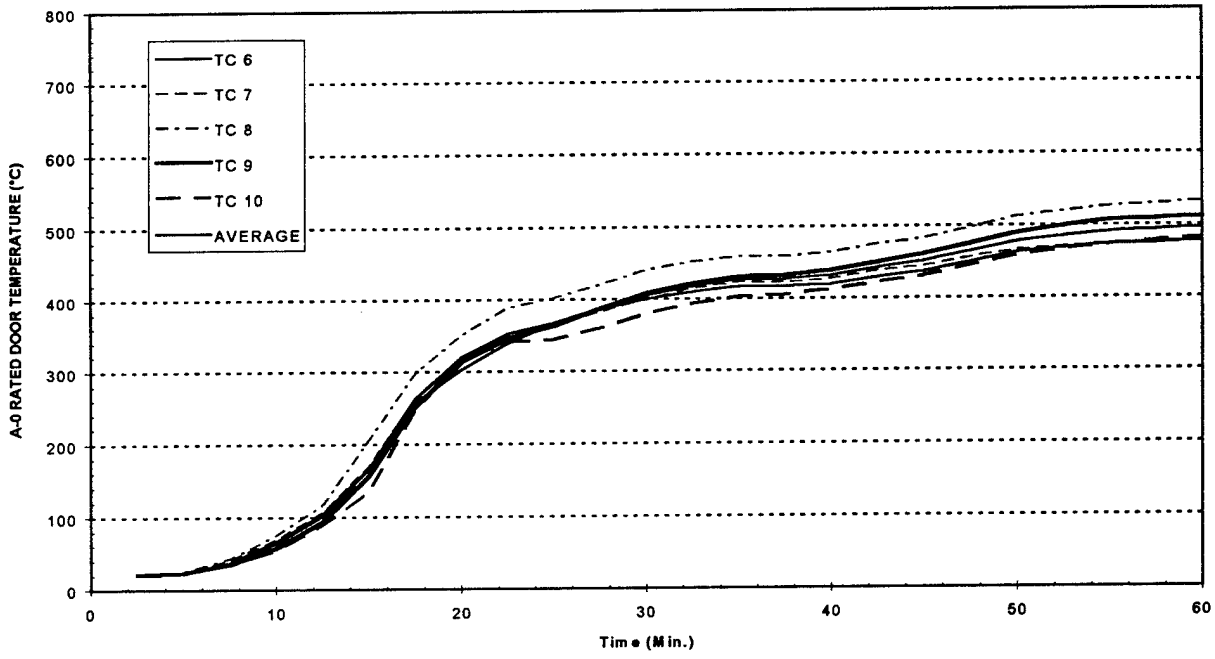


Figure D-12. Unexposed Surface Temperature: A-0 Fire Door (Sample 7)

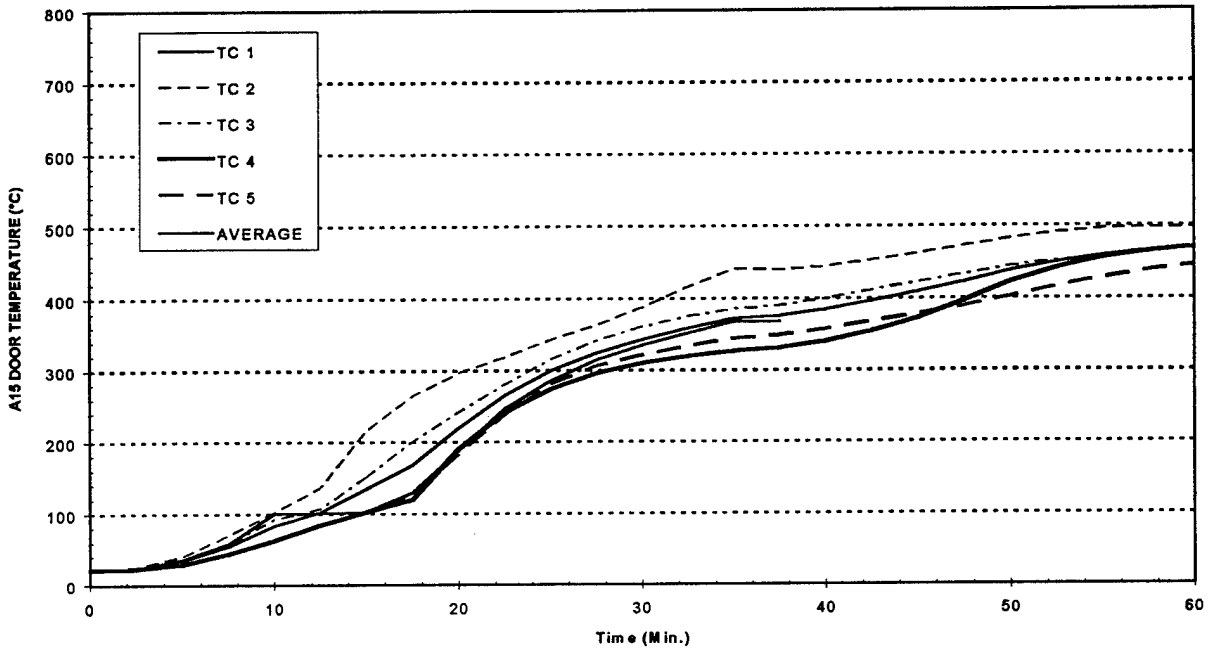


Figure D-13. Unexposed Surface Temperature: A-15 Fire Door (Sample 8)

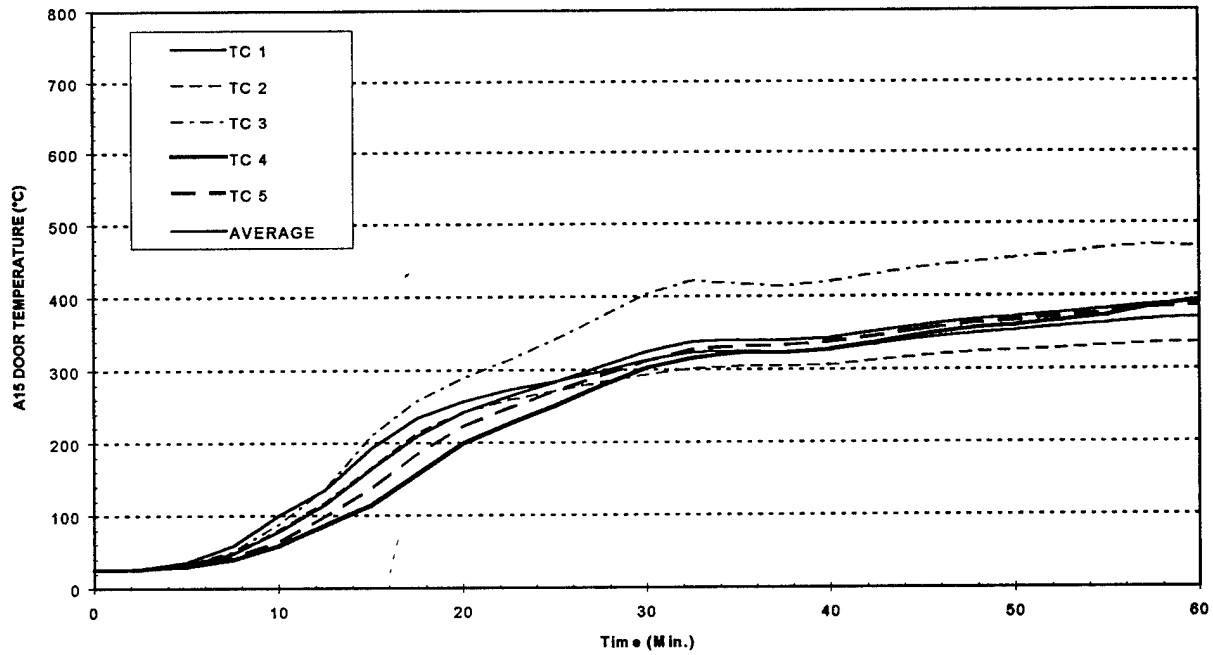


Figure D-14. Unexposed Surface Temperature: A-15 Fire Door (Sample 9)

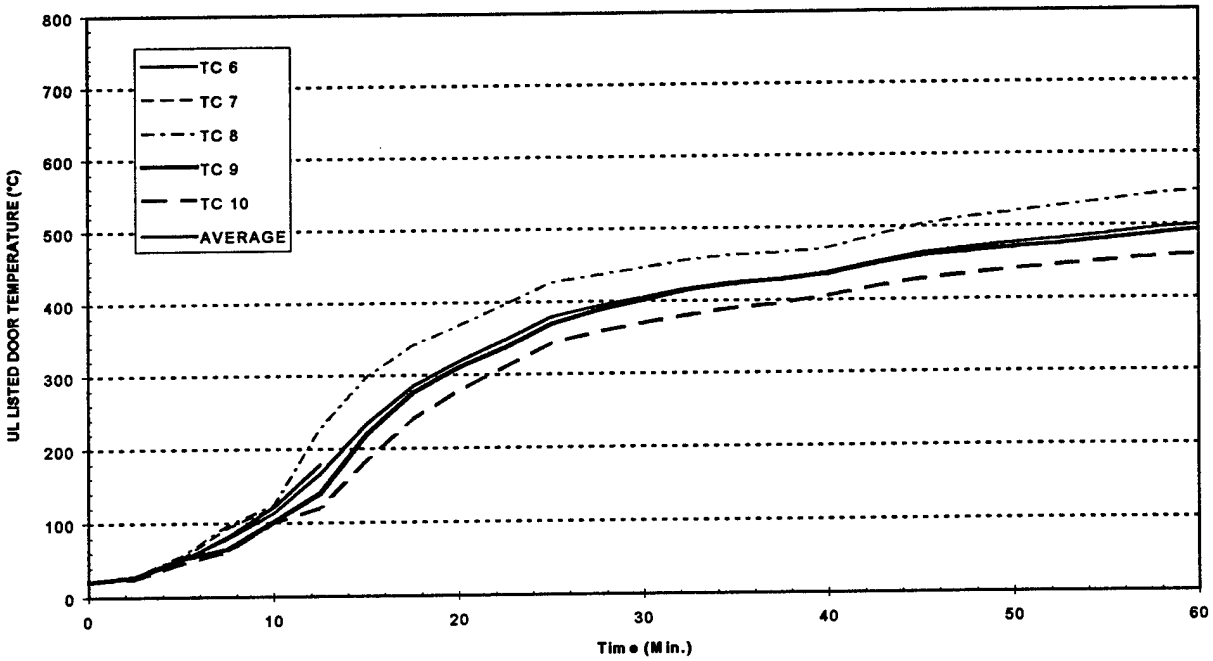


Figure D-15. Unexposed Surface Temperature : UL Listed 1-Hour Fire Door (Sample 10)

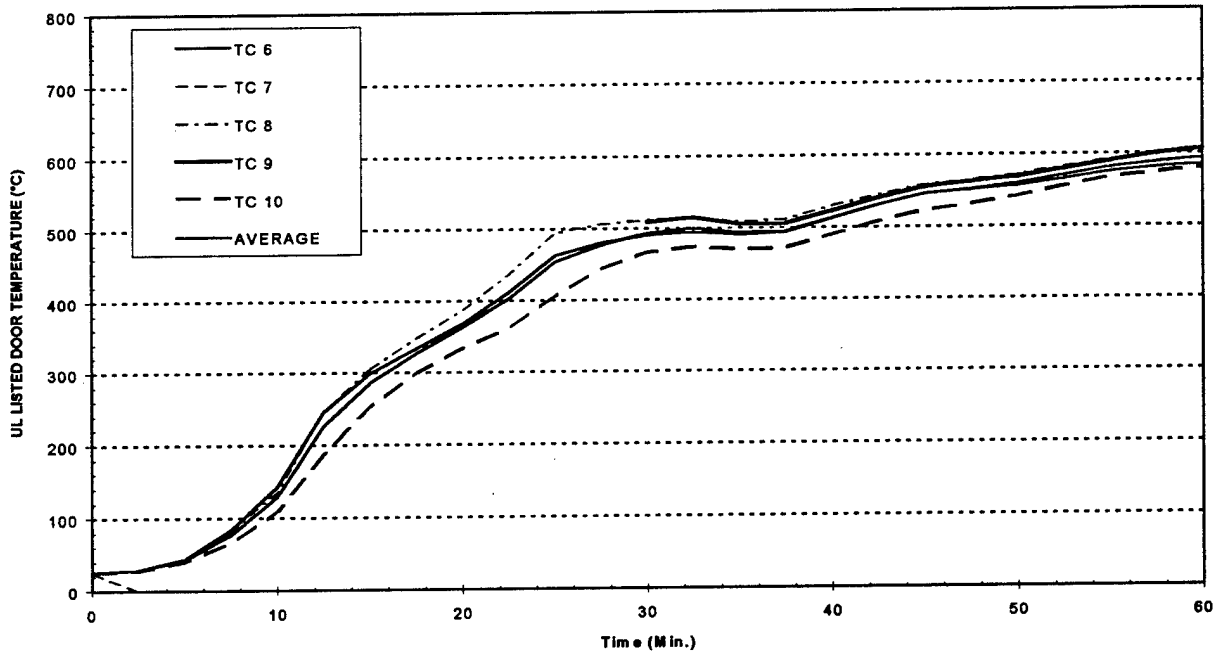


Figure D-16. Unexposed Surface Temperature : UL Listed 1-Hour Fire Door (Sample 11)

Appendix E
Fire Test Results - Observations and Deflections

Bulkhead A

Fire Stops and Dampers

Visual Observations 5/12/94:

Time min:sec	Observations
0:00	Gas on.
2:30 exp. side	The cable has ignited.
5:45	The south damper has closed.
6:45	Smoke is steadily emitting from the north duct.
6:58	The north damper has closed.
8:00 exp. side	The fire stop sealant is burning.
13:20	A cotton pad test is conducted on the gases emitted from the cable transit. (negative)
14:00	Steady smoke is being emitted from the cable transit and light intermittent smoke is being emitted from the pipe penetrations.
16:00 exp. side	The bulkhead face is deforming.
38:00	A cotton pad test is conducted on the gases emitted from the pipe penetrations. (negative)
45:00	A cotton pad test is conducted on the gases emitted from the cable transit. (negative)
55:00	There is heavy smoke from the cable transits.
60:00	Gas off. The fire stops are still burning on the exposed side. The flames are extinguished with a light application of water.

Deflection of Assembly Toward Furnace:

Time(min)	North	Center of Bulkhead	South
Datum	254	254	254
10	305	318	311
20	298	324	330
30	279	318	330
40	267	318	330

Bulkhead B

A-15 South Door: UL Rated 1 Hour North Door

Visual Observations 5/17/94:

Time min:sec	Observations
0:00	Gas on.
3:30	The spot welds are popping in both doors.
7:20	The entire bulkhead is noticeably deflecting towards the furnace. Light smoke is being emitted from the tops of both doors.
9:30	The top of the south door has a wavy deformation along the top.
10:00	A cotton pad test is conducted on the gases from the south door top (negative). The door skins are discoloring outlining the stiffener pattern.
14:20	T.C's #6 and 7 have disengaged from the sample.
34:00	The south door latch edge top corner has deflected towards the furnace away from the frame stop approx. 20 min.
36:00	A cotton pad test is conducted on the south door top edge where light licks of flames are noticed. (negative)
37:30	T.C. #1 has disengaged from the sample.
60:00	Gas off. The maximum separation of the north door top latch edge corner away from the frame stop is approx. 8 mm. All other locations are tight against the frame for both doors.

Deflection of Assembly Toward Furnace:

Time (min)	North	South
Datum	286	292
5	305	298
10	311	324
20	318	330
30	318	318
45	318	318

Bulkhead C

A-15 South Door: UL Rated 1 Hour North Door

Visual Observations 5/24/94:

Time min:sec	Observations
0:00	Gas on.
1:00	The spot welds are popping in both doors.
7:17	Light smoke is being emitted from the tops of both doors.
15:00	Light wisps of flame are noted from the top of the south door. A cotton pad test is conducted on the hot gases that are emitting. (negative)
60:00	Gas off. Both doors are tight up against the frame stops.

Deflection of Assembly Toward Furnace:

Time (min)	North	Center of Bulkhead	South
Datum	273	229	267
10	305	279	286
20	305	292	305
30	292	279	305
40	292	279	286

Bulkhead D

A-0 Fire Doors

Visual Observations 6/2/94:

Time min:sec	Observations
0:00	Gas on.
8:00	Light smoke is being emitted from the tops of both doors.
13:00	The door skins are beginning to discolor outlining the stiffener pattern.
30:00	The upper hinge edge corner of the north door has separated approx. 10 mm from the frame stop towards furnace. A cotton pad test is conducted on the hot gases that are emitting. (negative)
60:00	Gas off. The south door remained tight up against the frame. No further movement of the north door.

Deflection of Assembly Toward Furnace:

Time (min)	North	Center of Bulkhead	South
Datum	286	235	273
5	305	254	292
10	324	286	318
20	318	298	318
30	305	298	305

Bulkhead E

A-0 Fire Door

Visual Observations 6/7/94:

Time min:sec	Observations
0:00	Gas on.
23:00	The upper latch edge corner has separated 1/2 in. from the frame stop towards the furnace. A cotton pad test is conducted on the hot gases. (negative)
35:00	Steady flaming is noticed from the upper latch edge corner. The flaming is a result of furnace gas and air mixing through the door crack and combusting. The separation is approx. 3/4 in.
50:30	Both the latch edge corners have separated 3/4 in. towards the furnace.
60:00	Gas off. The door is unlatched but has not swung open or separated from the frame any further.

Deflection of Assembly Toward Furnace:

Time (min)	North	Center of Bulkhead	South
Datum	339	330	311
5	394	362	343
10	906	381	356
20	419	394	368

Appendix F
Leakage Test Data

Table F-1. Environment During Leakage Tests

Bulkhead	Pre Fire Test Environment				Post Fire Test Environment			
	Temperature	Barometric Pressure	Relative Humidity	Saturated Vapor Pressure [vii]	Temperature	Barometric Pressure	Relative Humidity	Saturated Vapor Pressure[vii]
	(°C)	(Pa)	(%)	(Pa)	(°C)	(Pa)	(%)	(Pa)
A	22.4	99395	33	2828	17.7	99302	42	2095
B	17.7	99954	40	2095	20.0	99848	29	2453
C	21.6	98980	59	2703	21.1	98102	56	2625
D	22.2	99419	40	2796	20.8	99723	52	2578
E	23.3	98710	54	2968	18.3	99216	60	2188

Table F-2. Pre Fire Test - Uncorrected Leakage Test Results

Test	Leakage Rate (m^3/hr)								
	@5 Pa	@10 Pa	@20 Pa	@30 Pa	@50 Pa	@70 Pa	@100 Pa	@5 Pa	@ Highest Static Pressure
Bulkhead A	6.9	8.6	10.6	12.4	15.1	17.9	23.9	3.7	22.3
Sample 1	36.5	43.8	60.6	75.2	75.6	93.5	116.0	18.8	117.3
Sample 2	30.9	46.4	67.0	85.9	98.0	121.3	148.9	60.0	150.9
Sample 3	5.4	7.3	10.0	12.6	17.1	21.6	27.9	6.2	28.1
Sample 4	1.1	4.5	7.7	10.6	15.5	20.1	23.5	4.9	29.5
Bulkhead A	6.6	8.4	11.3	14.0	18.8	23.6	30.1	6.9	29.7
Bulkhead B	39.3	47.5	60.7	70.4	86.9	74.5	88.4	27.6	87.6
Sample 8	375.3	419.8	499.1	615.9	689.0	790.7	922.9	386.4	928.2
Sample 10	OROR	368.7	470.7	565.4	706.6	774.3	928.2	217.6	934.1
Bulkhead B	27.4	31.3	38.0	45.1	57.0	65.3	78.5	25.6	76.9
Bulkhead C	29.5	32.0	34.4	42.6	50.4	58.6	93.0	OROR	93.0
Sample 9	358.8	382.5	457.1	522.5	642.0	741.2	872.6	363.7	871.6
Sample 11	373.8	427.1	500.7	571.9	694.4	812.5	939.9	389.8	941.8
Bulkhead C	24.2	26.2	29.1	31.5	38.3	42.1	49.4	22.8	50.0
Bulkhead D	14.5	19.4	26.6	31.5	42.6	50.4	61.0	17.9	59.6
Sample 6	351.5	387.9	467.8	522.0	640.6	751.0	876.4	357.8	878.4
Sample 7	351.5	406.3	495.4	559.3	701.6	827.5	967.5	372.9	970.9
Bulkhead D	25.2	31.5	43.1	50.4	59.6	70.2	78.0	29.5	78.9
Bulkhead E	24.7	28.6	31.5	35.8	43.6	49.9	58.1	27.1	58.6
Sample 5	611.1	648.4	717.1	787.8	900.6	1018.3	1153.9	617.4	1154.9
Bulkhead E	29.1	30.5	34.4	39.2	46.0	52.8	62.5	OROR	OROR

Table F-3. Post Fire Test - Uncorrected Leakage Test Results

Test	Leakage Rate (m^3/hr)								
	@5 Pa	@10 Pa	@20 Pa	@30 Pa	@50 Pa	@70 Pa	@100 Pa	@5 Pa	@ Highest Static Pressure
Bulkhead A	70.9	89.4	107.2	129.0	166.8	203.4	243.3	76.0	251.4
Sample 1	157.0	166.5	195.9	219.5	265.5	305.0	354.6	162.6	363.1
Sample 2	176.2	190.9	225.8	253.9	304.3	350.3	414.9	161.0	417.7
Sample 3	178.5	198.3	233.5	267.1	318.9	367.8	425.7	163.0	427.5
Sample 4	106.1	122.1	151.6	177.2	221.5	261.1	307.7	113.8	307.5
Bulkhead A	119.1	129.2	152.7	170.1	202.5	235.7	274.7	119.5	274.8
Bulkhead B	32.3	60.6	75.1	92.2	119.4	143.4	174.1	59.6	177.0
Sample 8	916.1	975.2	1097.1	1188.3	1411.1	1560.1	OR	907.5	1557.2
Sample 10	1036.0	1124.0	1240.7	1388.2	1597.9	OR	OR	1081.7	1605.2
Bulkhead B	67.5	76.6	88.6	101.7	124.0	143.8	168.8	70.2	170.4
Bulkhead C	98.3	137.6	183.5	217.4	290.2	355.4	443.1	160.3	450.8
Sample 9	834.3	896.3	1018.3	1126.5	1334.5	OR	OR	861.9	1335.0
Sample 11	757.6	845.0	1021.7	1138.4	1404.7	OR	OR	797.5	1418.8
Bulkhead C	215.5	240.2	276.1	303.6	356.6	414.0	486.2	215.0	483.7
Bulkhead D	46.0	71.2	106.0	130.7	172.9	216.0	262.9	79.4	262.5
Sample 6	411.6	596.1	801.4	982.5	1245.9	1539.3	OR	600.4	1525.3
Sample 7	588.8	715.2	951.5	1091.9	1387.3	OR	OR	676.9	1414.9
Bulkhead D	104.1	116.2	147.7	167.5	200.5	242.1	298.3	112.8	302.6
Bulkhead E	25.7	41.2	64.9	81.8	110.9	133.6	165.1	45.0	168.5
Sample 5	1114.2	1220.2	1515.6	OR	OR	OR	OR	OR	OR
Bulkhead E	75.5	78.9	142.8	OR	OR	OR	OR	75.0	OR

OR - Over the range of the leakage equipment

Table F-4. Pre Fire Test - Corrected Leakage Test Results

	Leakage Rate (m^3/hr)								
	@5 Pa	@10 Pa	@20 Pa	@30 Pa	@50 Pa	@70 Pa	@100 Pa	@5 Pa	@ Highest Static Pressure
Bulkhead A	6.7	8.3	10.3	12.0	14.6	17.4	23.2	3.6	21.6
Sample 1	35.4	42.5	58.8	72.9	73.3	90.7	112.6	18.2	113.8
Sample 2	30.0	45.0	65.0	83.3	95.1	117.7	144.5	58.2	146.4
Sample 3	5.2	7.1	9.7	12.2	16.6	21.0	27.1	6.0	27.3
Sample 4	1.1	4.4	7.5	10.3	15.0	19.5	22.8	4.8	28.6
Bulkhead A	6.4	8.1	11.0	13.6	18.2	22.9	29.2	6.7	28.8
Bulkhead B	39.0	47.1	60.2	69.8	86.2	73.9	87.7	27.4	86.9
Sample 8	372.0	416.1	494.8	610.6	683.2	784.2	915.6	383.0	920.9
Sample 10		365.5	466.6	560.5	700.7	768.0	920.9	215.7	926.7
Bulkhead B	27.2	31.0	37.7	44.7	56.5	64.8	77.9	25.4	76.3
Bulkhead C	28.5	30.9	33.2	41.1	48.7	56.6	89.9		89.9
Sample 9	346.5	369.4	441.5	504.7	620.2	716.2	843.5	351.2	842.5
Sample 11	361.0	412.5	483.6	552.4	670.9	785.1	908.5	376.4	910.3
Bulkhead C	23.4	25.3	28.1	30.4	37.0	40.7	47.7	22.0	48.3
Bulkhead D	14.1	18.8	25.8	30.6	41.3	48.9	59.2	17.4	57.9
Sample 6	340.9	376.2	453.7	506.3	621.5	728.8	850.7	347.0	852.7
Sample 7	340.9	394.0	480.5	542.5	680.7	803.0	939.2	361.6	942.5
Bulkhead D	24.4	30.5	41.8	48.9	57.8	68.1	75.7	28.6	76.6
Bulkhead E	23.6	27.4	30.2	34.3	41.8	47.8	55.7	25.9	56.2
Sample 5	585.1	620.8	686.7	754.5	862.7	975.6	1105.9	591.1	1106.8
Bulkhead E	27.9	29.2	32.9	37.5	44.1	50.6	59.9		

Table F-5. Post Fire Test - Corrected Leakage Test Results

Test	Leakage Rate (m^3/hr)								
	@5 Pa	@10 Pa	@20 Pa	@30 Pa	@50 Pa	@70 Pa	@100 Pa	@5 Pa	@ Highest Static Pressure
Bulkhead A	69.8	88.0	105.6	127.0	164.3	200.4	239.8	74.8	247.7
Sample 1	154.6	163.9	192.9	216.2	261.5	300.5	349.4	160.1	357.8
Sample 2	173.5	188.0	222.3	250.0	299.7	345.1	408.9	158.5	411.6
Sample 3	175.7	195.2	229.9	263.0	314.1	362.3	419.5	160.5	421.3
Sample 4	104.5	120.2	149.3	174.5	218.2	257.2	303.2	112.0	303.0
Bulkhead A	117.3	127.2	150.4	167.5	199.5	232.2	270.7	117.6	270.8
Bulkhead B	31.7	59.6	73.8	90.6	117.4	141.0	171.3	58.6	174.1
Sample 8	900.3	958.5	1078.4	1168.2	1387.5	1534.3		891.9	1531.9
Sample 10	1018.2	1104.7	1219.5	1364.7	1571.1			1063.1	1579.1
Bulkhead B	66.3	75.3	87.1	100.0	121.9	141.4	166.1	69.0	167.6
Bulkhead C	94.3	132.0	176.0	208.6	278.5	341.1	425.4	153.7	432.8
Sample 9	800.2	859.7	976.8	1080.7	1280.6			826.7	1281.7
Sample 11	726.6	810.5	980.1	1092.2	1347.9			764.9	1362.1
Bulkhead C	206.7	230.4	264.9	291.3	342.2	397.3	466.8	206.2	464.4
Bulkhead D	44.9	69.5	103.5	127.7	168.9	211.1	257.0	77.5	256.6
Sample 6	401.9	582.2	782.7	959.7	1217.2	1504.2		586.3	1491.0
Sample 7	575.0	698.5	929.3	1066.6	1355.4			661.0	1383.0
Bulkhead D	101.7	113.5	144.3	163.6	195.9	236.6	291.6	110.2	295.8
Bulkhead E	25.2	40.4	63.6	80.2	108.7	131.0	162.0	44.1	165.3
Sample 5	1091.9	1195.9	1485.5						
Bulkhead E	74.0	77.3	140.0					73.5	